THE DEVELOPMENT OF LATENT FINGERMARKS ON PAINTED WALLS

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PhD Thesis

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Abstract

This research aimed to determine which fingermark processes are most efficient at developing latent marks on internal walls that have been painted. At present there is a deficiency in the quality and quantity of fingermarks being recovered from such substrates by practitioners working in the field. This issue is amplified by a lack of published research in this area. Therefore, this in-depth study sought to address some of the key challenges faced by practitioners and fill the void of knowledge in this specific area.

Various methodologies were employed to undertake this research, beginning with a survey of practitioners to gauge the current practices in use across the UK. This assisted in determining the most commonly used processes to develop latent fingermarks on painted walls and the types of scenes in which painted walls are likely to be investigated. The detail gained from the questionnaire then informed the design of the experimental work carried out within this research. The experimental work consisted of numerous smaller studies to tackle specific research questions, exploring variations of paint types and brands to ascertain if these have an effect on deposited fingermarks from different donors, and establishing the primary differences between paint types and categorising these into coherent groups. The results from these studies then assisted in constructing the final set of methodologies investigating which processes are most effective at developing fingermarks on different paint types.

The results from this research highlighted that practitioners do not always consider the texture or composition of a painted wall before attempting to develop latent fingermarks. In addition to this, practitioners do not generally follow the published guidelines from the Home Office Centre for Applied Science and Technology (now DSTL). The findings from the experimental work revealed that there is a distinct difference between matt paints and other non-matt paints (such as silk and bathroom paint) and therefore they should be processed differently by practitioners. The most effective treatment for matt painted walls is cyanoacrylate vapour (dyed with basic yellow 40), whereas the most efficient process for non-matt painted walls is black magnetic granular powder.

This research culminated in a proposed set of guidelines designed for fingermark practitioners to assist them in creating fingermark recovery strategies. The guidelines have been constructed upon rigorous scientific evidence and should significantly increase the quality and quantity of latent fingermarks being developed '*in situ*' on painted walls.

Key words: Fingermarks, Matt paint, Silk paint

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Chapter 1 - Introduction

Fingerprint and fingermark evidence is one of the oldest and most established forms of forensic evidence (Hamilton, 2013). Fingerprints are defined as ridge detail impressions that originate from a known individual, whereas fingermarks are defined as ridge detail impressions from uncontrolled contact between a person and a substrate (Forensic Science Regulator, 2017a). There is a long history regarding fingerprints and their use within the court system, which started in ancient China (Ashbaugh, 1999). However, fingermark research, both from an academic and practitioner's view point, still requires much work. There are still many surfaces '*in situ*', such as painted walls, where the quality and quantity of recovered fingermarks are limited; potentially leaving fingermarks undetected at scenes (Flynn, et al., 2004).

Therefore, this research aims to fill the gap in knowledge regarding the development of latent fingermarks on painted walls. It is imperative to establish which fingermark development processes are currently being used on painted walls in the United Kingdom (UK) by practitioners, in order that these can be compared to literature, highlighting any similarities and differences. Therefore, this study began by exploring published research in this area, which is limited, and thus a thorough review of other related literature was carried out. It was also necessary to explore published research regarding paint types and general wall construction to fully understand the effects these may have on latent fingermarks that are deposited on painted walls.

1.1. Properties of paints

Surface coatings can be defined as:

> *"a mixture or dispersion of opaque pigments or powders in a liquid or vehicle and may include organic and inorganic coatings such as enamels, varnishes, emulsions, bituminous coatings etc"* (Master Painters Institute, 2015).

The coating industry subcategorises these different surface coatings further as 'varnishes' and 'paints'. Varnishes are further defined as unpigmented coatings that allow the surface to be visualised after application, whereas paint is a pigmented coating, which is combined with binders and solvents (Bentley, 2001). This research will focus purely on paints (specifically architectural emulsion paints), rather than varnishes, as this is where the current gap in knowledge lies and therefore additional research is vital.

The binder (also referred to as the resin or polymer) is the component that adheres the constituents of the paint together to form a continuous cohesive film. The function of the solvent is primarily to assist in the application of the paint. Together, the binder and solvent have an effect on some of the properties of the finished paint, such as toughness, durability and drying time (Bentley, 2001; Master Painters Institute, 2015). Kitchens and bathrooms are good examples of where durability is vital, and therefore manufacturers use either vinyl polymers or acrylic polymers for high sheen and better performance (Bentley, 2001). Overall, aqueous emulsion paints have become very popular with domestic consumers and constitute around 80% of the market (Paint Quality Institute, 2015). Pigments are the main constituents found within paint, and provide colour and opacity. They can be categorised into three main groups; natural inorganic, synthetic inorganic and synthetic organic. It is the type and quality of the pigments that often determines the overall price of the paint (Bentley, 2001).

1.1.1. Pigment volume concentration

Paint research and production is discussed in terms of volume, rather than weight, and can be differentiated by its pigment volume concentration (PVC). Asbeck and Van Loo, (1949) established that the PVC is determined by evaluating how much of the total solid paint (excluding all volatile components) is composed of pigments, and can be calculated using the following formula:

$$PVC = \left[\frac{(Pigment\ Volume)}{(Pigment\ Volume + Vehicle\ Solids\ Volume)}\right] x\ 100$$

(National Institute of Industrial Research, 2006)

PVC has a significant effect on paint, as shown in Table 1. Paints with higher PVC (such as matt paint) are able to hide imperfections in walls more easily, however the durability and glossiness of the paint diminishes, and they become porous (Strauch, 2001).

Table 1 - The effect of PVC of finished paint product
(Table adapted from Resene, 2003, p5).

As PVC increases...			
DECREASES	Gloss	INCREASES	Hiding power
	Exterior durability		Density
	Scrubbability		
	Adhesion		

Different paints will have different levels of PVC. According to the Paint Quality Institute (2004), the typical values associated with different sheens (that are available to the general public for 'DIY' purposes) are:

- 15% PVC – Gloss,
- 25% PVC – Semi-gloss,
- 35% PVC – Satin (and silk),
- 35-45% PVC – Eggshell,
- 38-80% PVC - Flat (matt).

Flat matt paint, as shown above, has a much higher PVC (between 38-80%) than other paint types, such as gloss (15%). This provides a matt powdery appearance, which is relatively porous (Hansen, et al., 1994). Due to the increased porosity of the paint, matt painted surfaces have increased permeability, and therefore a decreased level of strength and flexibility (*ibid*). This leaves the painted surface more susceptible to the effects of oxygen, water and humidity, and therefore likely to degrade at a much faster rate than paint with a lower PVC (Bentley and Turner, 1998).

In addition to these environmental factors, latent fingermarks may also be absorbed into paints that have a high PVC due to the increased porosity of the surface (Daluz, 2015). This can be problematic for Crime Scene Examiners (CSEs), as they only carry powders to develop latent fingermarks, which are only appropriate to use on semi-porous and non-porous substrates where the mark remains on the surface (Hamilton, 2013; Bandey, et al., 2014). Therefore, latent fingermarks may not be developed on painted walls if the paint is porous, as the fingermarks will already have been absorbed into the surface. This would require the use of other chemical/physical treatments which can only be applied by trained Fingerprint Laboratory Officers (FLOs), who do not routinely attend volume crime scenes (Charlton, 2009). This research aims to address this key issue in order that practitioners can make informed decisions regarding development processes when *'in situ'*.

1.1.2. Critical pigment volume concentration

Critical pigment volume concentration (CPVC) is the point at which the binder within the paint just fills the voids between the pigment particles, which have become densely packed together (Lobnig, et al., 2006). Above CPVC, the properties of the paint, such as permeability, roughness and gloss, rapidly change and voids form between the densely packed pigment particles (Wang, et al., 2014).

Figure 1 shows the relationship between pigments and binders at various levels of PVC. Paints with a PVC of 30 have particles that are embedded into the binder layer, producing a smoother surface, whereas paints with a PVC of 75 protrude greatly from the binder, producing a textured surface (Lobnig, et al., 2007b)

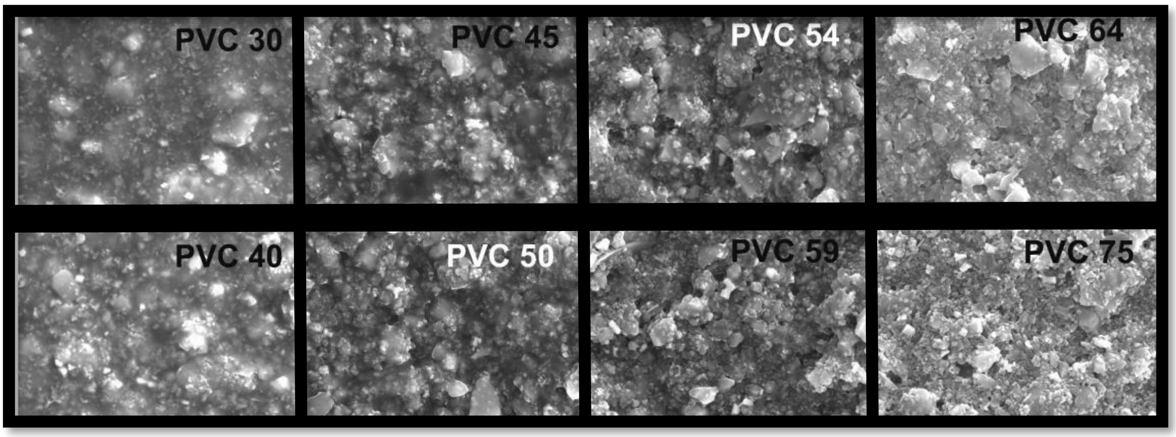


Figure 1 - Scanning Electron Microscopy (SEM) images of the surface of coatings at PVC 30% to 75%
(Lobnig, et al., 2007b).

CPVC can be determined via various experimental methods, such as measurement of internal stress, contrast ratio, gloss, and calculation from oil absorption values (Panda, 2010). In addition to these traditional methods, Lobnig, et al., (2006, 2007a, 2007b) developed a new method using electrochemical impedance spectroscopy (EIS), which can be used to detect the CPVC of various coating types. However, Feller and Kunz (1981) state that on average, CPVC falls between 30% and 65% PVC. This means that the majority of matt paint, with PVC of 38-80%, is specifically produced above CPVC level, in order to provide consumers with a product that has greater hiding power for any wall defects and low sheen. This also means that it is more porous, and therefore latent fingermarks are likely to be absorbed into the surface (Paint Quality Institute, 2004; Bandey, et al., 2014).

1.1.3. Popularity of paint types

The Paint Quality Institute (2015) states that aqueous paints are most frequently purchased by domestic consumers compared to solvent based paints. This is primarily due to the European Union (EU) introducing legislation (EU Directive 2004/42/EC - subsequently updated in January 2010) to limit the harmful volatile organic compound (VOC) levels in paint, thus reducing VOC levels entering the environment. Water based emulsion paints also have supplementary vinyl/acrylic polymers added to the paint to increase the toughness and resistance of the finished paint, making them more hardwearing (Learner, 2004).

However, there is a gap in knowledge about how popular each paint type is (i.e. matt, silk, etc.). Therefore, it is imperative to ascertain the most commonly purchased paint type to determine the frequency that Scene Examiners may encounter these at crime scenes. In order to establish which paint type is most popular, three of the most prominent home improvement stores in England (Homebase, B&Q and Wickes) were contacted for assistance. Two (Homebase and B&Q) were unable to help with the request, however Wickes provided two years' worth of paint sales data for 2013-2014 (Wickes, 2015). Nevertheless, the number of customers that opted for wallpaper in lieu of, or in addition to architectural paint is unclear.

The data contained a number of details relating to the paint, such as type, colour, brand, and volume, in addition to the quantity and cost of each. The most popular paint types that could be applied to walls (excluding gloss and satin wood paints) were collated from both years and compared, and an average frequency was established. Figure 2 shows the results of the most popular paint types sold at Wickes (in descending order according to the average for both years).

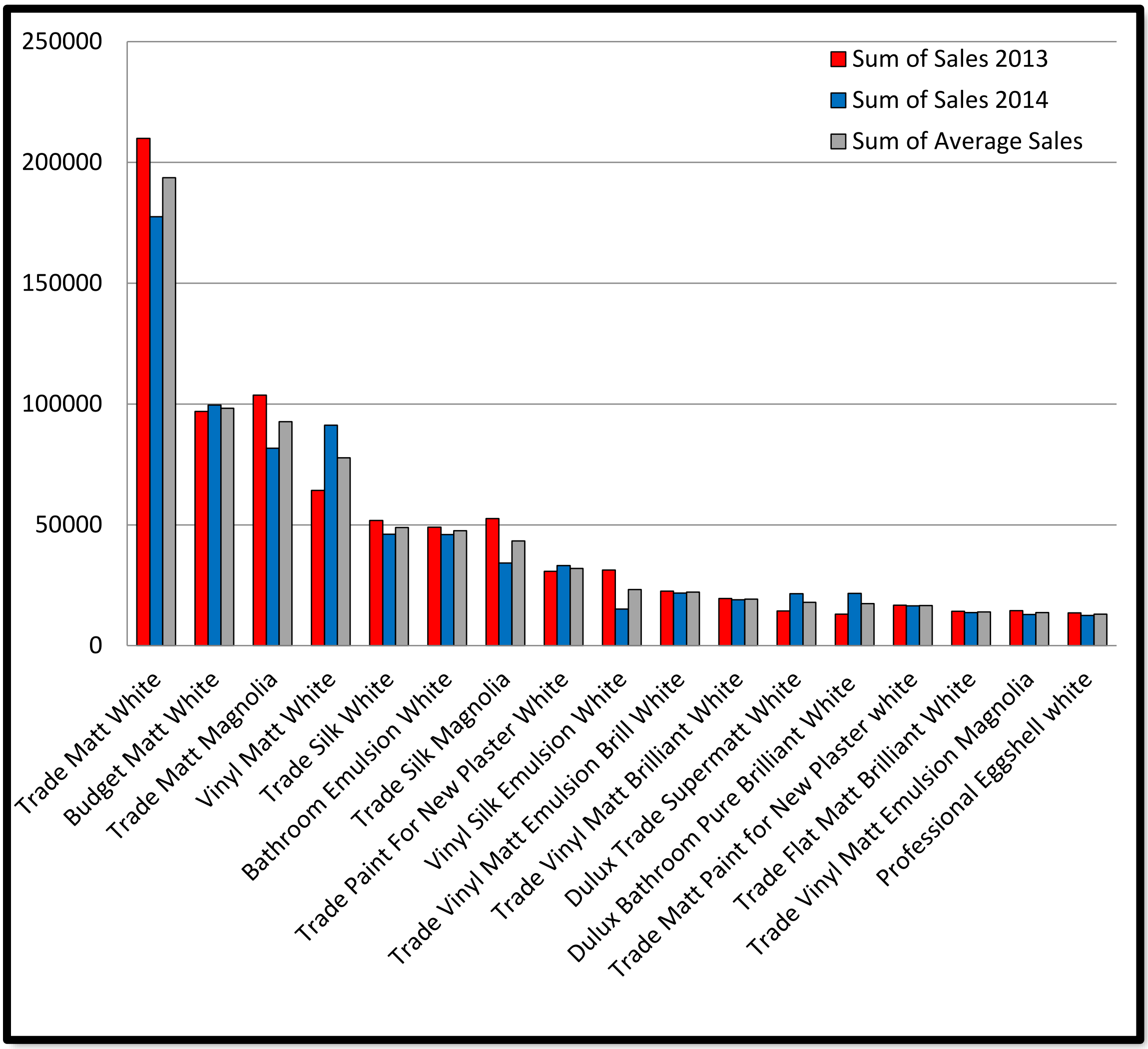


Figure 2 - Most popular architectural wall paints sold by Wickes between 2013-2014.

The most popular paint type sold by Wickes was matt paint (Figure 2). Of the most frequently sold paints (Figure 2), 59% were of a matt type with “Trade Matt White” being purchased the most. The data also shows that white, was the most popular colour chosen by consumers, with 82% of paints being that colour. These findings are in agreement with those published by Bentley (2001). Therefore, the likelihood of encountering matt painted walls at a crime scene is much higher than any other paint type. This is problematic due to this paint type being porous and Crime Scene Examiners only having access to non-porous fingermark development processes (Charlton, 2009); thus highlighting the need for this research.

Whilst considering the different porosities of paint types, it is also important to explore the construction of walls in the UK. Both the composition of the paint, and the wall itself, may have an effect on latent fingermarks that are deposited on walls at crime scenes. The construction of walls using differing materials may have an effect on the thermal properties and airflow, thus increasing or decreasing the rate of fingermark degradation (Frick, et al., 2013). In addition to this, the topography of the finished internal walls may also have an effect on the deposition of fingermarks, as an increase in texture (from either the wall finish, or the use of wall paper) will result in intermittent fingermarks (Bandey, et al., 2014).

1.2. Construction of walls in domestic premises

Walls of houses are constructed to provide shelter against the weather, and offer security to the inhabitants. They should also be resistant to ground moisture, fire and heat and prevent a percentage of noise from entering (Emmitt and Gorse, 2014). External walls have been constructed in many ways from simple rubble walls with lime mortar, to Flemish bond single course brickwork, to cavity walls, which now include some form of insulation (University of West of England, 2009). Therefore, it is important to consider that variations of wall types may have a differing effect on any fingermarks that are deposited on internal surfaces.

To ascertain the most common type of wall construction found in houses within England, statistics have been collated through the English Housing Survey (Department for Communities and Local Government, 2012) and are presented in Figure 3. These statistics also include the proportion of households that are owned or rented, as this may have an effect on the quality of upkeep that the houses have received, which may subsequently affect the development of latent marks deposited on the walls (*ibid*).

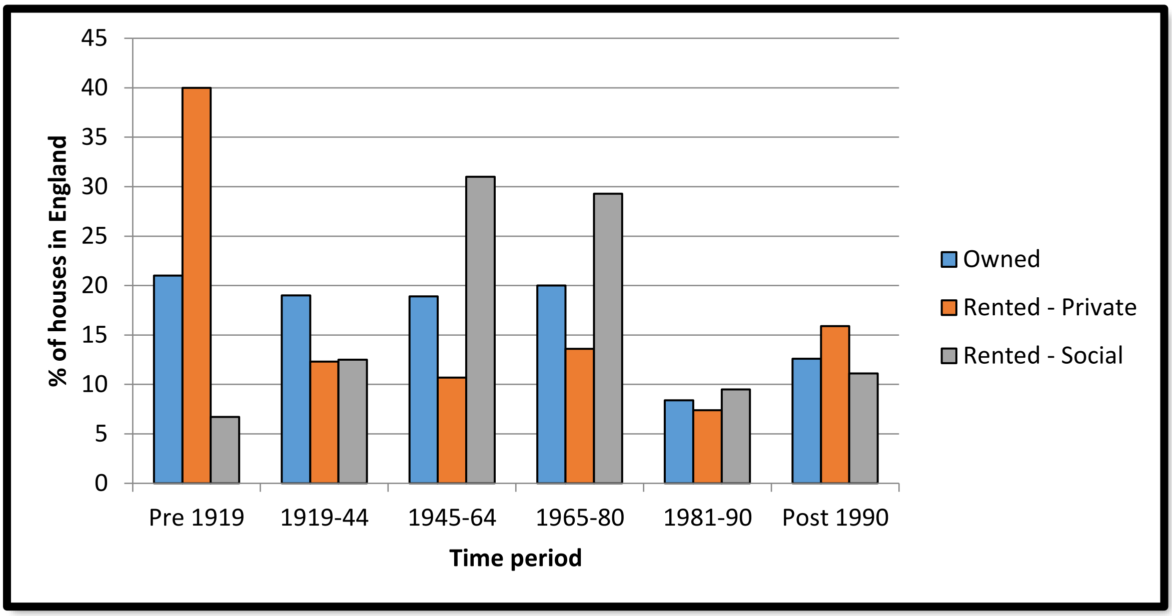


Figure 3 - Statistics for the age and occupation of properties in England
Adapted from Department for Communities and Local Government (2012).

There are a wide age range of houses in England (Figure 3), which is important to recognise, as the methods in which these were built will vary according to the technology available at the time of construction. Cavity wall construction was developed throughout the twentieth century, and became very popular throughout Europe after World War Two (Hens, et al., 2007; Emmitt and Gorse, 2014). Therefore, houses in England post-1945 are primarily constructed with cavity walls, and those pre-1945 with a single solid wall. A small minority of houses were also constructed with more eco-friendly materials such as timber and straw bales (Emmitt and Gorse, 2014). Blockwork is often used to construct the inner walls of modern premises, allowing for cavity walls. This has improved thermal properties and is quicker to construct due to the blockwork being of a larger size compared to traditional bricks (Hendry and Khalaf, 2000). The blockwork can be plastered over for a finer finish before decoration. In general, walls are deemed to be '*airtight*' once they have been covered with at least one coat of plaster to prevent unwanted airflow (Baurmann, et al., 2013).

Therefore, the construction of the walls should not have an effect on the airflow surrounding deposited latent fingermarks once a layer of plaster has been applied. However, as Barry (1999) highlights, Gypsum wallboard, which is most commonly used in modern domestic premises, can be carefully joined together to create a smooth finish which can be decorated without the need for a plaster finish (Figure 4). If plaster is not applied then the walls may not be 'airtight' and therefore the flow of air around deposited fingermarks could affect their longevity and subsequent development. This indicates the need for further research in this area, to ascertain whether or not the finish of the internal wall has an effect on the development (and ageing) of fingermarks.

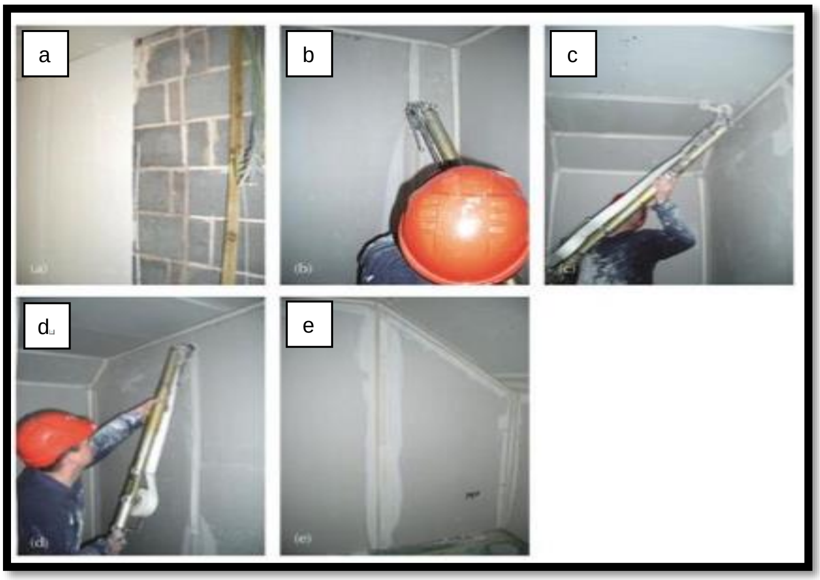


Figure 4 (a-e) - Photographs showing: (a) plasterboard being adhered to a blockwork wall, (b-d) joints of plasterboard being taped and skimmed, (e) joints left to dry and subsequently sanded
(Emmitt and Gorse, 2014, p590).

However, Gypsum wallboards can also be adhered to the internal surface blockwork and used as a base for a layer of finish plaster before decorating. The finish plaster (which is powdered, hemihydrate gypsum) should be spread between 2 to 5 mm thick to create a fine, smooth finish (Barry, 1999). If additional depth is needed to create a smooth finish then is it common for a base coat of more coarse plaster to be applied first with the more finely finished plaster on top. However, this requires time to allow each layer to fully dry before applying the next layer (Watts, 2013).

Alternatively, it is possible to apply plaster directly to the internal surface of the blockwork (Figure 5). This can be carried out either by using a one-coat plaster, which should be applied to a thickness of 11-13 mm, or two coats of fine plaster to gain a smooth finish to the wall (Barry, 1999). Whilst one-coat plaster negates the need for drying time between successive applications of fine plaster, it can be more difficult to achieve a smooth finish (Emmitt and Gorse, 2014). The internal plaster or plasterboard surfaces can then be decorated with either wallpaper or paint; the latter of which is the focus of this study. However, it is important that the plaster is fully dry prior to the application of any paint; otherwise this may have a detrimental effect on the quality of the finished wall.

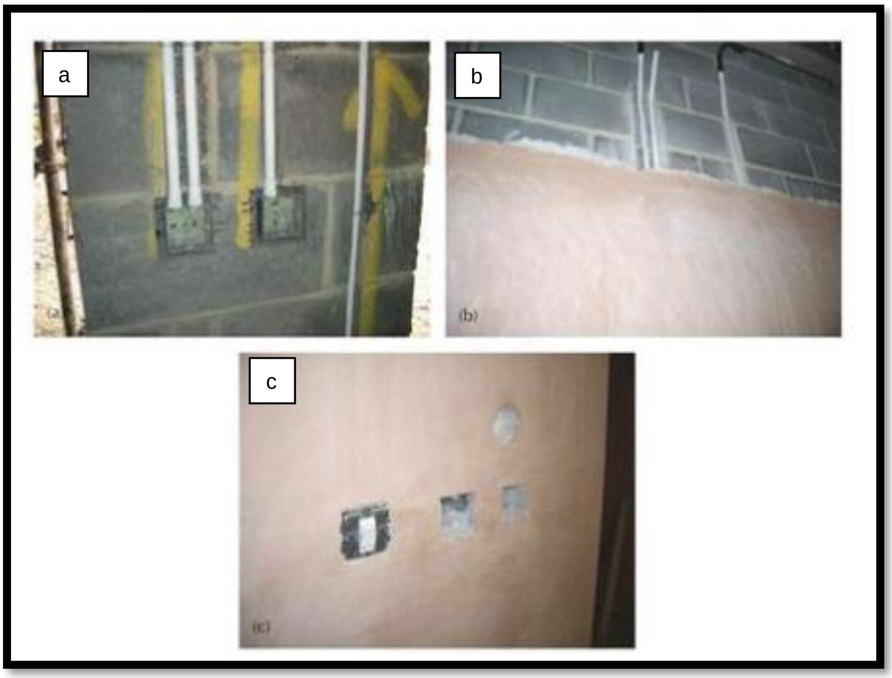


Figure 5 (a-c) - Photographs showing: (a) surface prior to application of plaster/render, (b) surface after base coats and finish coats applied, (c) surface after finish coat applied (Emmitt and Gorse, 2014, p579).

The texture of an internal wall (substrate) is likely to have an effect on the deposition and subsequent development of fingermarks (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014). This highlights the need for further research, not only regarding effective development processes (Chapters 2 and 4), but also the topography of painted walls (Chapter 3).

1.3. Factors affecting the deposition of fingermarks

Texture and porosity of the substrate are key issues for this study, but they are not the only factors affecting the development of latent fingermarks. Elasticity/rigidity of the substrate must also be considered, along with the composition, pressure and age of the fingermarks, in addition to environmental factors such as temperature, humidity, light and airflow, as shown in Figure 6. All three of these elements will have an impact on the suitability and the effectiveness of the development process chosen, as described later in this chapter (Archer, et al., 2005; Fieldhouse, 2011b; Girod, et al., 2012; Bandey, et al., 2014).

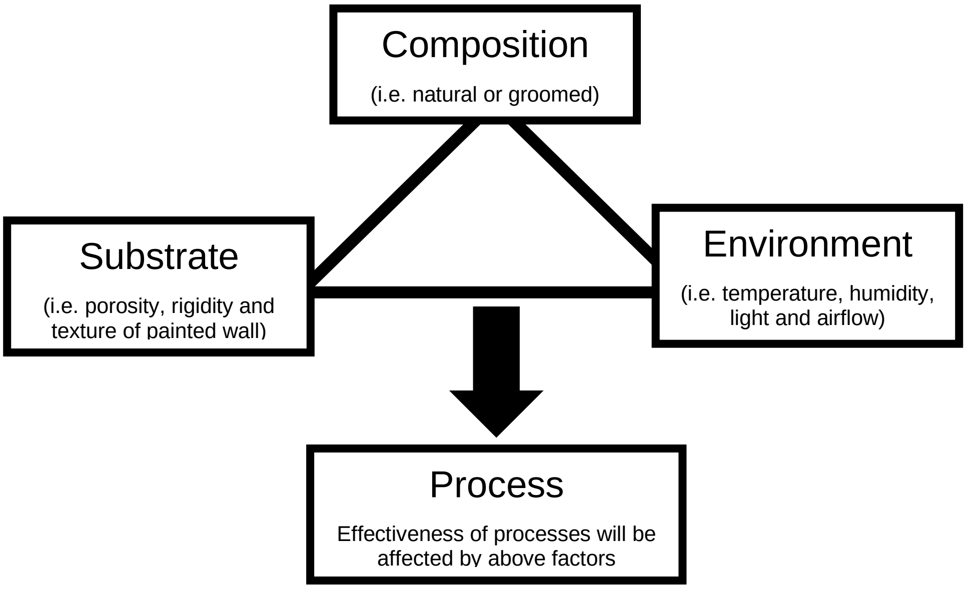


Figure 6 - Fingermark triangle of interaction (adapted from Cadd, et al., 2015).

The fingermark triangle of interaction displayed in Figure 6 must be considered when designing methodologies for fingermark research, ensuring that all experimental parameters are disclosed (i.e. age and storage conditions of marks, composition of marks and formulation of solutions, to name a few) (Sears, et al., 2012; International Fingerprint Research Group, 2014). It is impossible to test all of these variables in a study of this size, and therefore this research will primarily concentrate on the issues of the porosity of paint and the texture of painted walls, and the effectiveness of development processes on aged fingermarks.

1.3.1. Composition of latent fingermarks

One of the main variables to be considered is the composition of latent fingermarks donated by research participants, as the inter- and intra-variability between donors is significant (Frick, et al., 2013; Stubbs, et al., 2015; Chadwick, et al., 2018). Latent fingermarks primarily consist of residues secreted from the eccrine glands (Table 2), as these are the only glands present on the palmer surfaces (Maceo, 2011). However, hands also come into contact with other areas of the body, and therefore are likely to be contaminated with other endogenous secretions from the sebaceous (and apocrine) glands (Bécue and Cantú, 2013; Frick, et al., 2013).

The precise combination of these constituents will vary in a fingermark according to gender, age, diet and medication (Frick, et al., 2013). The amino acid content of fingermarks (particularly asparagine), varies according to gender, with higher concentrations noted in fingermarks donated by females compared to males. Conversely, male fingermarks have a higher concentration of fatty acids compared to those from female donors (Croxton, et al, 2010; Cadd, et al, 2015). Fingermark constituents also varies according to diet, with higher concentrations of some amino acids (alanine, glycine and serine) found in fingermarks of vegetarian donors, compared to those with an omnivorous diet (Croxton, et al, 2010). In addition to the endogenous substances outlined in Table 2, latent fingermarks may also contain semi-exogenous compounds such as caffeine, those from medication or those from substance misuse (Rowell, et al., 2009). Furthermore, fingermarks may also be contaminated with substances, such as hair products and make-up, or illegal substances, which could provide investigators with information relating to the donor’s lifestyle (Girod, et al., 2012).

Table 2 – Inorganic and organic constituents of fingermark residue from eccrine, sebaceous and apocrine glands
(Adapted from Bandey, et al., 2014).

Gland	Inorganic Constituents	Organic Constituents
Eccrine glands	Ammonia Bicarbonate Bromide Chloride Fluoride Iodide Metal ions - major Metal ions - trace Phosphate Sulphate Sulphide Water	Amino acids Creatine Creatinine Enzymes Glucose and other reducing sugars Glycogen Lactic acid and lactate Peptides Phenols Proteins Pyruvic acid and pyruvate Urea Uric acid Vitamins
Sebaceous glands		Alcohols Fatty acids Fatty acid alkyl esters Glycerides Hydrocarbons Squalene Squalene degradation products Sterols Sterol esters Wax esters
Apocrine glands	Ammonia Iron Water	Androgenic steroids Carbohydrates Carboxylic acids Proteins Sterols

In order to control the variability associated with donor fingermarks, it is possible to use latent print reference pads (TETRA Scene of Crime, 2016; Sirchie, 2016). This allows for a uniform print to be deposited on each occasion for research purposes. However, the quality of these synthetic pads vary and should not be assumed to behave as real fingermarks, which differ greatly due to donor intra- and inter-variability (Sears, et al., 2012; Frick, et al., 2013). Nevertheless, for initial stages of research, they are acceptable to use, as they can be effective indicators as to whether or not the research methodology is robust and should be progressed further using a large number of real donor fingermarks (Sears, et al., 2012; International Fingerprint Research Group, 2014).

1.4. The comparison of fingermarks

There are two distinct ways in which fingermarks are analysed and compared, depending upon whether it is for identification (i.e. criminal investigations) or research purposes. For identification purposes, practitioners follow the 'ACE-V' process, which involves analysis, comparison, evaluation and verification (Tierney, 2013). The analysis step of this process involves assessing the Level 1, 2 and 3 details present in the marks (Table 3). For an identification to be made, there must be no inconsistencies in the details between the fingermark found at the crime scene and the suspect's fingerprints (Hamilton, 2013).

Table 3 - Analysis of fingermarks for identification purposes
(Compiled from Hamilton, 2013)

Level	Description
Level 1	Pattern type and ridge flow found within the fingermark (i.e. arch, loop, whorl)
Level 2	Ridge characteristics found within the fingermark (i.e. bifurcations, ridge endings)
Level 3	Pores and ridge edge shapes (i.e. size and location of pores, irregularity of ridge edges)

There are differing standards in place throughout the world on the number of matching characteristics that are required in order to determine a match (Hamilton, 2013). Since 2001, there has been a non-numerical standard in the UK, requiring Fingerprint Examiners to demonstrate how a conclusion was arrived at (Champod, 2013). The change in standard (which previously required 16 matching level 2 characteristics) now means that experts can take other features, such as clarity of marks and the relationship between the characteristics, into account (Knowles, 2000; Ulery, et al., 2013). Fingerprint Bureaux throughout the UK must be accredited to ISO 17025 standards, as per the Forensic Science Regulator's codes of practice and conduct (Forensic Science Regulator, 2017a). Although fingerprint identification has been used in the criminal justice system for over a century, there is limited research available regarding the impartiality of Experts and the credibility of fingerprint evidence for identification purposes (Dror, et al., 2011).

Until recently, fingerprint identifications had rarely been challenged in court and were seen as a reliable form of evidence (Neumann, 2013). However, Saks (2003) argues that fingerprint evidence has been accepted in the past because: -

> *“they were flying the banner of science and not because they present sound data supporting their claims”.*

Researchers are currently developing statistical models to assess the weight of evidence that should be given to fingerprint identifications in each individual case, which will allow juries to assess and compare the weight of all forensic evidence presented (Desai and Jajal, 2009; Neumann, et al., 2012; Langenburg, et al., 2012). This is necessary to prevent further miscarriages of justice, such as the Mayfield case, where fingerprint evidence from the Madrid bombing in 2004 was misused by the FBI, resulting in wrongful arrest and detention (Office of the Inspector General, 2006).

A thorough understanding of the identification process is vital for fingermark researchers; however, it is inappropriate to use this system for research purposes, due to time constraints and lack of detailed identification training. Therefore, alternative systems are utilised to assess the quality, and the grade of the fingermarks produced during research. The University of Lausanne and the University of Canberra have developed different grading scales (International Fingerprint Research Group, 2014), although the most widely used grading system has been developed by the Home Office, which can be adapted to suit the needs of each particular study (Sears, et al., 2012). Whilst such grading systems are more efficient than using the ACE-V process, they are still subjective and require all fingermarks to be assessed by the same person (Sears, et al., 2012). However, marks graded by multiple assessors can be compared, showing that similar trends have been observed among samples, providing confidence in the grading process (Fritz, et al., 2015). Nevertheless, data collected during this process can then be analysed, and appropriate statistical models applied, to ascertain the significance of the results. The Home Office grading system will be used for this research in order that the data can be statistically analysed and the significance of results reported throughout.

1.5. The development of latent fingermarks

There are a large number of fingermark development processes that have been reported to develop latent fingermarks via optical, chemical or physical methods; with varying levels of success (Yamashita and French, 2011). Most of these processes have been designed for, and are used in, a controlled laboratory environment by FLOs, where safe working practices are in place, protecting laboratory personnel and working in accordance with ISO 17025 standards *(*Forensic Science Regulator, 2017b).

However, these processes cannot be transferred to crime scenes where the environment may be unpredictable, requiring further considerations, such as the health and safety of those working in the scene, in addition to those that may live in the premises after the investigation is complete (Kent, 2013b). It is also important to note that practitioners (both CSEs and FLOs) have limited control over processing conditions '*in situ'*, requiring additional validation work to be carried out in order to meet the requirements of ISO 17020 accreditation (Forensic Science Regulator, 2017c). Also, the mess caused by development techniques, and therefore the subsequent cleaning of the scene, need to be taken into account too. It is vital that the most appropriate processes are used in the correct sequence when examining walls '*in situ*' at crime scenes, as most techniques are destructive and cannot be reversed once used (Bandey, et al*.,* 2014).

1.5.1. Optical methods to develop fingermarks

Optical methods, such as the use of high intensity light sources, are generally non-destructive for both fingermarks and the substrate, with the aim of providing contrast between the two in order that the mark can be visualised (Daluz, 2015). These techniques can be used at various points within a sequential process to either further define a mark, or visualise additional marks that may have been developed using a chemical treatment (Bandey, et al., 2014). Specific wavelengths of high intensity light sources can be applied to a mark, allowing some of the energy to be absorbed, which is then emitted at a longer wavelength, providing a different colour (Figure 7). Light sources of different wavelengths can be used to search for latent marks on any untreated item, regardless of surface type (Bleay, et al, 2017).

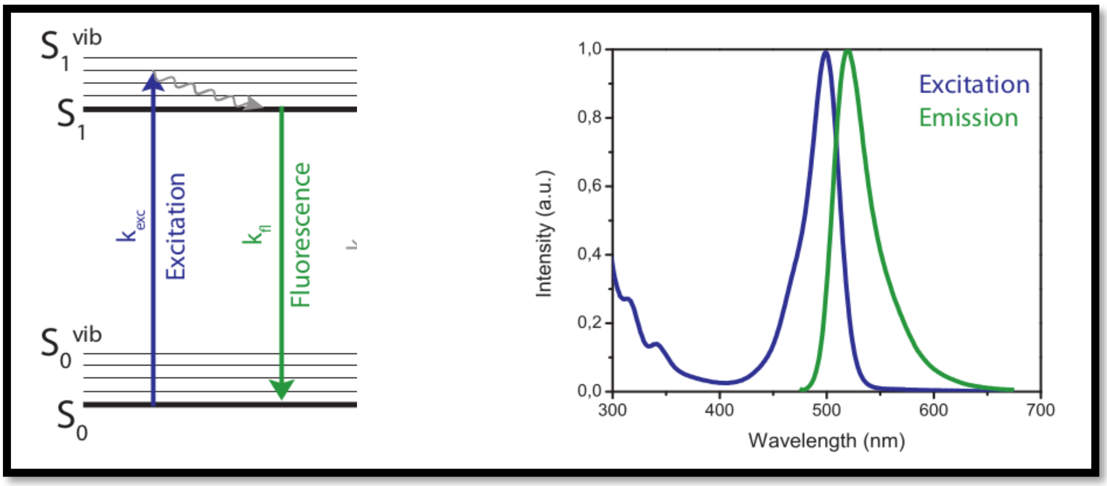


Figure 7 - Jablonski diagram illustrating the transition of energy leading to fluorescence, with accompanying excitation and emission profile (adapted from Scientific Volume Imaging B.V., 2016).

Due to the lack of sample preparation and non-destructive capabilities of this technique, high intensity light sources should be used first within all sequential treatment processes (Trozzi, et al., 2000). However, the process of examination is time consuming and it is therefore generally reserved for serious crimes scenes, such as murder (Lee and Gaensslen, 2001). As high intensity light sources are always present at the beginning of any sequential workflow, these will not be explored in any depth during this research, but they will be used to further enhance and visualise fingermarks that have been developed using other processing methods.

One lighting method that does have a detrimental effect on latent fingermarks is Ultra-Violet (UV) light (Kumar, et al., 2015; Nakamura, et al., 2015). Short-wavelength UV light (< 310 nm) is useful in detecting marks on various surfaces, but not only does this carry a health and safety risk, it also degrades DNA held within a latent mark that may be of interest to investigators (Lennard, 2001). Therefore, this particular process should be used with caution and only on latent marks where DNA is not required. Alternative optical and spectroscopic methods have also been researched to locate latent fingermarks. An example of this is the use of Fourier Transform Infrared (FTIR) imaging to detect and further enhance fingermarks (Tahtouh, et al., 2005; Tahtouh, et al., 2007; Tahtouh, et al., 2011).

However, this laboratory technique would be difficult to apply '*in situ,*' which is the focus of this study. Merkel, et al., (2012) explored the use of 2 dimensional and 3 dimensional chromatic white light image sensors to analyse fingermarks. Such techniques are non-invasive and can be utilised '*in situ*' at scenes to not only locate, but also capture fingermark images. Whilst such technological advances provide promising results, they need further validation before being considered for purchase by Scientific Support Departments. Although optical methods are considered to be non-destructive, they require specialist equipment and specific risk assessments if used at scenes, as per chemical/physical processes. Therefore, optical methods are primarily utilised by FLOs, rather than CSEs, as they are specially trained in the use of high intensity light sources and the subsequent imaging of any fingermarks, as per ISO 17020 accreditation. The health and safety of the personnel working within the scene must be considered carefully in addition to members of the public (Kent, 2013b). For this study, consideration is given to these techniques as the initial step in a sequential process and to further enhance developed marks; however, the main focus is on the use of chemical and physical development processes, which are safe to use '*in situ*' at crime scenes.

1.5.2. Chemical/physical methods to develop fingermarks

Chemical/physical development processes are split into two main categories; those suitable for porous substrates (i.e. paper, and cardboard), and those for non-porous substrates (i.e. plastic and glass). These can be further sub-divided into groups according to texture and composition of the substrates (Yamashita and French, 2011; Bandey, et al., 2014). Semi-porous substrates are treated using a combination of porous and non-porous development processes, according to the type of substrate (*ibid*). In this research different paint types have been divided into separate categories on the basis of their porosity (i.e. matt is porous, silk is semi-porous, gloss is non-porous), and therefore it is necessary to explore all chemical and physical processes for this research.

1.5.2.1. Processes used to develop fingermarks on porous substrates (including matt paint)

When latent marks are deposited onto porous surfaces, the majority of the constituents are drawn into the substrate itself, leaving a few remaining non-soluble components on the surface (Jasuja and Singh, 2009). It is therefore vital that the methods used on porous surfaces are also absorbed into the substrates in order to react with the soluble constituents present. There are a number of development processes available for porous substrates (Table 4 and Table 5), however some are more efficient than others. The Home Office Centre for Applied Science and Technology (CAST) have categorised each process according to its efficacy and reliability (Bandey, et al*.,* 2014):

- Category A – standard processes that should be used;
- Category B and C - optional processes for occasional operational use;
- Category D - corrective action processes;
- Category E and F – processes should not be used as no operational benefits known, or due to health and safety concerns.

A small number of chemical and physical techniques (category A) are recommended to be used in sequence to maximise the yield of latent fingermarks developed once a visual and fluorescence examination has taken place (Table 4) (*ibid*). Only processes in categories A to D will be considered in this study, as per Home Office guidelines, and only those suitable for latent fingermarks on painted walls will be discussed in this chapter (Table 4-8).

It is important to note that only FLOs (and not CSEs) are trained to apply porous processes, both at crime scenes and in the laboratory. FLOs only attend serious crime scenes and therefore porous processes are not used '*in situ*' at volume crime scenes.

Table 4 - CAST recommended sequential processing of latent fingermarks on porous surfaces
(adapted from Bandey, et al*.,* 2014).

Process	**In sequential order**	**CAST category**	**Ability to use on painted walls?**
DFO (1,8-Diazafluoren-9-one)	1	A	**Yes** – breathing apparatus required, reaction time varies according to environmental conditions, and requires fluorescence examination
Ninhydrin	2	A	**Yes** – breathing apparatus is required, and reaction time varies according to environmental conditions
Physical Developer (followed by enhancement)	3	A	**No** – requires submersion in three separate solutions

Table 5 - Additional processes for latent fingermarks on porous surfaces
(adapted from Bandey, et al*.,* 2014).

Process	**CAST Category**	**Ability to use on painted walls**
DMAC (4-dimethylaminocinnamaldehyde)	B	**Possible** – surface needs to be pressed against DMAC impregnated sheets and wrapped in foil
Indandione	B[1]	**Yes** – breathing apparatus required, reaction time varies according to environmental conditions, and requires fluorescence examination
Iodine Fuming	B	**Yes** – breathing apparatus is required, and developed fingermarks fade
Iodine Solution	B	**Yes** – breathing apparatus may be required, and developed fingermarks fade.
Oil Red O	B	**No** –messy and difficult to clean-up due to heavy background staining
Silver Nitrate	B	**Yes** – requires light source for development and difficult to clean-up
Genipin	C	**Yes** - marks are faint and requires additional fluorescence examination, and reaction time varies according to environmental conditions
Nile Red	C	**No** – requires submersion in separate solutions/water

[1] *At present Indandione is a category B process, but DSTL will reclassify this to a category A process in the next edition of the Fingermark Visualisation Manual. At the same time, DFO will be reclassified from a category A process to a category B process – essentially interchanging the two processes (Sears, 2017)*

1.5.2.1.1. Recommended Category A processes (DFO and ninhydrin)

1,8-Diazafluoren-9-one (DFO) is generally the most sensitive and effective technique in developing fingermarks on porous substrates (Wilkinson, 2000; Yamashita and French, 2011). It reacts with the amino acids present in fingerprint secretions (Knowles, 1978; Ramotowski, 2001). It has previously been reported that there is on average 250 ng of amino acids per fingermark (Hansen and Joullié, 2005). DFO needs a high-temperature, low-humidity environment in order to develop latent marks to their full potential (Yamashita and French, 2011). Although this is possible to use on painted walls at crime scenes, it is rarely used due to the difficulties in maintaining sufficient heat for the reaction to complete (Kent, 2013b).

Once developed, it leaves a faint pink/red mark on the substrate, which may faintly be seen with the naked eye. However, when excited between 473-548 nm (green region) the mark fluoresces orange (Bleay, et al., 2017). Hence, marks developed with DFO can be difficult to visualise and photograph '*in situ*' at scenes due to the need for fluorescent lighting (Bandey, et al*.,* 2014). This can be particularly problematic at crime scenes where lighting is not easily controlled. Therefore, this process will not be explored as part of this research.

Consequently, in practice the most commonly used development method on porous substrates is ninhydrin, as this does not require fluorescent lighting to visualise developed marks (Yamashita and French, 2011). Ninhydrin is another amino acid reagent, which was first documented by Ruhemann (1910) who noted its strong colour reaction (pink/purple) with amino acids – now named '*Ruhemann's purple*' (Ramotowski, 2013a). This process will be examined in detail throughout this research.

In the UK it is recommended that ninhydrin is processed in a high-temperature and humid environment in order to develop latent marks to their full potential (Kent, 2013b). This is problematic when used at scenes, where it is difficult to control both the temperature and the humidity. If a painted wall was too cold/dry, then the amino acids would not fully react with the ninhydrin solution, producing partially developed marks (Ramminger, et al., 2001). Although the reaction of ninhydrin is visible to the naked eye, it can be further treated with metal salts, such as zinc chloride, to induce fluorescence. These additives can be included in the ninhydrin solution (one-step process), or can be used to treat marks once developed using ninhydrin (two-step process) (Almog, et al*.,* 2007).

When comparing DFO and ninhydrin together (as both single and sequential processes), DFO out-performs ninhydrin, as it is a more sensitive process (Mink, et al*.,* 2013). Regardless of the sensitivity of both processes, neither DFO nor ninhydrin are recommended for use on wetted items, due to substantial loss of amino acids (Bandey, et al*.,* 2014). Whilst water is not an issue when examining painted walls within most crime scenes, it would be problematic in bathrooms, which are constantly subjected to water and moisture in the air. In addition to this, fire scenes that have been extinguished with large amounts of water will pose a significant problem and therefore this must be taken into consideration when designing fingermark recovery plans.

Although DFO and ninhydrin are the recommended processes to use on porous surfaces (Bandey, et al*.,* 2014), there are considerable issues regarding the use of both techniques at scenes, due to the requirement for controlled heat (and humidity for ninhydrin). In addition to this, the clean-up procedure involves removing and destroying all wall/floor coverings where possible, and all walls should be sealed using diluted polyvinyl acetate (PVA), before redecoration takes place (Home Office Scientific Development Branch, 2007). Due to these issues, it is particularly difficult to develop latent fingermarks on walls that are painted with porous high PVC paints, such as matt, thus highlighting the need for this research.

1.5.2.1.2. Category B processes (indandione, iodine fuming/solution, silver nitrate)

The effectiveness of indandione to develop latent marks on porous substrates has been discussed in recent years (Lee and Joullié, 2015; Mangle, et al*.,* 2015). Lam and Wilkinson (2011) state that indandione outperformed DFO by developing more marks with improved fluorescence, thus suggesting that indandione should replace DFO in routine casework. CAST have also explored new formulations of indandione to ascertain its effectiveness against DFO, with success (Sears, 2017). Therefore, this process will be included in this research. Nevertheless, there are still issues surrounding the use of indandione to develop latent marks on painted walls at scenes.

The reaction between amino acids and indandione is most effective when at high temperatures, which can be difficult to achieve at scenes where the area to be treated is large (Bandey, et al*.,* 2014). However, indandione does react at lower temperatures compared to DFO, and therefore may be more suitable for use '*in situ*'. Nevertheless, indandione developed marks require fluorescence examination, which can also be problematic at scenes (Nicolasora, et al., 2018a). Therefore, both DFO and indandione pose the same issues if used at scenes.

Conversely, iodine processing does not require fluorescence examination and can be viewed by visual examination alone. Iodine can develop fingermarks by either applying the solution directly onto the substrate, or via fuming (Ramotowski, 2013c). However, the developed marks are temporary, and therefore must be recorded and analysed immediately (Kent, 2013b). Iodine solution was once recommended as the most effective process to develop latent fingermarks '*in situ*' on walls at crime scenes (Pounds, et al., 1986; Pounds, 1989; Pounds, et al., 1992). Subsequent research found that ninhydrin (Chlorofluorocarbon (CFC) based formulation) was more effective at developing latent fingermarks on painted walls than iodine. Therefore, ninhydrin is now the recommended process (Bleay, et al*.,* 2013).

Contemporary methods for both processes were further assessed in 2009, which demonstrated that the current iodine (heptane-based) solution was more efficient in developing latent fingermarks compared to current ninhydrin (CFC-free) solution (Fletcher, 2009). Therefore, iodine solution will be explored during this research. However, it is important to note that iodine fuming is both toxic and corrosive, and the heptane-based solutions are flammable, thus neither are suitable for use at crime scenes (Home Office Scientific Development Branch, 2007; Kent, 2013b; Ramotowski, 2013c). This emphasises the importance of this research in order to identify the optimum process that can be applied at scenes.

Silver nitrate is a process that reacts with the chlorides present in fingermark residue, turning a brown/grey colour (Ramotowski, 2013b). It is regarded as being less effective than physical developer, and therefore is not recommended for standard casework (Bandey, et al*.,* 2014). Recently silver nitrate has been applied to bricks and stones in order to develop latent marks with success (Davis and Fisher, 2015). The results of the study are of interest to this research, due to the composition and texture of the walls that fingermarks have been deposited on. Therefore, this process will be examined as part of this study. The silver nitrate reaction is most effective when the treated area is subjected to short-wavelength UV light, however due to health and safety concerns, blue or long-wavelength UV light is more commonly used, although this reaction is slower (Yamashita and French, 2011). The use of UV lighting at crime scenes could be problematic due to the safe working requirements of personnel and therefore needs careful consideration before being included in fingermark development workflows for scenes, as mentioned earlier in section 1.5.1.

1.5.2.1.3. Category C processes (Genipin)

Genipin is another amino acid reagent that can be used to develop latent marks on porous surfaces. This technique produces blue ridge detail, which also fluoresces red at 590 nm (Almog, et al., 2004). The reagent is composed of extracts from the Gardenia fruit (*Gardenia jasminoides*), which is beneficial for scene usage, as it is harmless and environmentally friendly (Levinton-Shamuilov, et al., 2005). However, it is not as effective as DFO and ninhydrin on paper substrates, providing poor contrast between fingermarks and the substrate. Therefore, it is not generally recommended as an enhancement method and will not be examined in this research (Bandey, et al., 2014).

1.5.2.2. Processes for non-porous substrates (including gloss paint)

Unlike porous items, non-porous substrates do not absorb fingerprint residues, thus leaving all constituents on the outer surface of the object, which can easily be damaged or destroyed (Flynn, et al., 2004). Therefore, different techniques should be utilised on these substrates in order to develop these marks more carefully. As per porous surfaces, there are numerous techniques available to develop marks on non-porous surfaces; a proportion of which are recommended by CAST for standard use (Table 6), with additional processes placed into appropriate categories (A-D) as shown in Table 7 (Bandey, et al., 2014). Only processes that can be applied to painted walls will be discussed in more detail in this section. It is important to note that the majority of non-porous processes still have to be applied '*in situ*' by FLOs, limiting such processes to major crime scenes. However, any fingerprint powders that are used at scenes are usually applied by CSEs, meaning that powders can be applied to both volume and major crime scenes.

Table 6 - CAST recommended sequential processing of latent fingermarks on non-porous surfaces
(adapted from Bandey, et al., 2014).

Process	In sequential order	CAST category	Ability to use on painted walls?
Vacuum Metal Deposition	1	A	**No** – surface needs to be in vacuum
Powders	2	A	**Yes** – easy to apply on vertical surfaces
Superglue Fuming (with additional dye)	3	A	**Yes** – but specific equipment needed due to health and safety issues during processing. One-step processes may be useful (negating the need for additional dyes)
Powder Suspension	3	A	**Yes** – but messy and difficult to clean-up
Basic Violet 3 (Phenol-based)	4	A	**No** – due to health and safety issues from post-processing residues

Table 7 - Additional processes for latent fingermarks on non-porous surfaces
(adapted from Bandey, et al., 2014)

Process	CAST Category	Ability to use on painted walls
Electrostatic Detection Apparatus (ESDA)	A	**No** – surface needs to be placed on apparatus
Gelatin Lifting	A	**Yes** – usually used post-powdering, but gelatin lifters can also be used to lift latent marks, although marks may degrade.
Multi-Metal Deposition	A	**No** – surface needs to be submerged in solutions
Small Particle Reagent	A	**Yes** – spray application is less effective than dish submersion and is messy and difficult to clean-up
Solvent Black 3	A	**Yes** – messy and difficult to clean-up as insoluble
Europium Chelate	B	**Yes** – ineffective on general latent marks and requires fluorescence examination
Natural Yellow 3	B	**Yes** – messy, difficult to clean-up and requires fluorescence examination
Single Metal Deposition	C	**No** – surface needs to be exposed in solutions
Disulphur Dinitride	C	**No** – surface needs to be in vacuum
Tagged Nanoparticles	C	**No** – are created to only ‘tag’ specific components within fingermark secretions and are not commercially available

1.5.2.2.1. Recommended Category A processes (powders, cyanoacrylate fuming and powder suspension)

Powders are the most commonly used method to develop fingermarks '*in situ*' at scenes as they can be applied to many surface types, including painted walls (with varying amounts of success). According to Bandey, et al., (2013), factors that are thought to influence the adhesion of powder to a fingerprint are:

- Particle shape,
- Surface chemistry of the powder particle,
- Electrostatic charge on the particle,
- Adhesion to grease or liquid,
- Low(er) adhesion to substrate.

As powders adhere to grease or liquid, they will also adhere to other aqueous elements that are present on the surface. This should not be problematic as long as the substrate is dry when powdering. However, if the material is wet, then a paint-like substance will be formed if the powder combines with the water, obliterating any fingermarks that have been deposited on the surface (Charlton, 2009). Conventional fingermark powders are comprised of a "*resinous polymer for adhesion*" and a "*colourant for contrast*" (Olsen, 1978). However, there are a wide range of modern powders available that can be utilised at crime scenes; some of which are versatile, whereas other have specific, but limited use.

Powders are generally divided into two main categories; flake or granular (Sodhi and Kaur, 2001). These classifications of powder correlate to the microscopic shape of the particles that make up the powder (Figure 8). The majority of CSEs prefer to use flake powders. This could be due to flake powders having a higher surface area, allowing better contact with the fingerprint residues, and negating the need for photography prior to lifting in most circumstances (Bandey, et al., 2013; Bandey, et al., 2014).

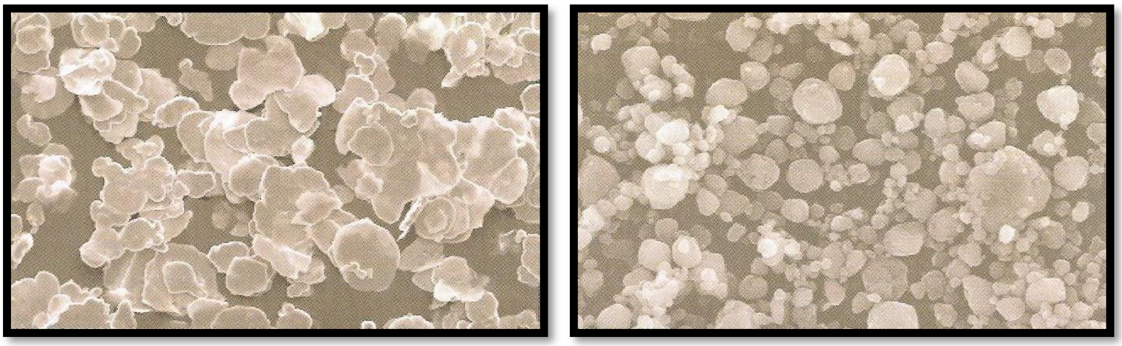


Figure 8 - SEM Images showing flake powder (left) and granular powder (right) (Bandey and Gibson, 2006).

The most commonly used powders by CSEs in the UK are aluminium flake, brass flake, magneta flake, black magnetic granular and black granular (Bandey, 2007). Whilst CSEs are free to select which powders to use (often using multiple powders one at a scene), a survey conducted by the Home Office Scientific Development Branch showed that aluminium powder was used at 76% of crime scenes attended, showing a clear preference for this particular powder (Bandey and Gibson, 2006). The survey also showed that magneta flake was used at 25% of crime scenes and black granular was used at 8% of scenes (*ibid*). However, CSEs should assess each surface prior to powdering and use the most appropriate powder for the substrate (as per Home Office guidelines), rather than their preferred powder (Charlton, 2009). Therefore, whilst CSEs may routinely prefer to use aluminium powder, they may deem this inappropriate to use on painted walls and therefore use a more suitable alternative.

There are a number of powders being researched which not only develop latent marks, but can then be analysed to detect certain compounds found within the fingermark residues, such as explosives and drugs (Rowell, et al., 2009; Ferguson, et al., 2011; Rowell, et al., 2012; Bradshaw, et al., 2013). However, specific analytical instruments are required to analyse the endogenous and exogenous compounds present in the fingermarks, gaining data that needs to be interpreted by trained personnel; thus, preventing such techniques from being used by CSEs at present.

Other developmental powders being are also being researched, such as silica gel G and anti-Stokes powders, which may have niche applications in the future (Ma, et al., 2012; Singh, et al., 2013). The application of nanoparticles to develop fingermarks has also been investigated, with different variations being used to form fingermark nanopowders, with different capabilities, such as tagging or fluorescence (Bai, et al., 2012; Saif, 2013; Algarra, et al., 2014; Moret, et al., 2016). Due to particle size, nanopowders should provide better contrast between fingermarks and the substrate, with much less background staining, which could be beneficial for painted walls. (Choi, et al., 2007; Choi, et al., 2008).

One form of these advanced nanopowders is commercially available, containing silica nanoparticles, which can be used as a powder or in powder suspension form (ArroGen, 2015). However, the efficacy of such powders compared to contemporary powders used by CSEs has not yet been compared on a large scale and therefore any advantages of using nanopowders to develop latent fingermarks on painted walls are not yet identified.

Whilst powders are the most commonly used non-porous technique at crime scenes (due to CSEs attending both volume and major crime scenes), there are alternative processes available that can be applied by FLOs, although both roles must adhere to ISO17020 standards when working at scenes. Cyanoacrylate vapour, which is also known as superglue fuming, is a technique commonly used to develop fingermarks on non-porous surfaces (Lewis, 2013). During this reaction, cyanoacrylate monomer polymerises on fingermark ridges. However, the precise mechanism to instigate the polymerisation of superglue is not yet fully understood (Yamashita and French, 2011; Lewis, 2013; Kent, 2013b). Wargacki, et al*.,* (2007; 2008) suggest that water-soluble amines and carboxylic acid groups in fingermark deposits are likely to be the initiators, whereas Bandey, et al., (2014) suggest that water (with the assistance of sodium chloride) found within eccrine deposits are likely to aid the polymerisation process.

Different research groups have suggested various reaction conditions in order to achieve optimal enhancement of fingermarks (Algaier, et al., 2011; Bleay, et al., 2013; Bandey, et al., 2014). The Home Office recommend heating ethylcyanoacrylate (Superglue) to 120 ^{o}C in a humid environment (between 75% and 90% relative humidity) (Bandey, et al*.,* 2014). Contrary to this Algaier, et al*.,* (2011) found that when heating the superglue to lower temperatures (20 ^{o}C) the yield of polymer produced was much higher, regardless of the relative humidity. However, in order to fully evaluate results, it is imperative that the experimental conditions are comparable. Algaier, et al*.,* (2011) did not use a conventional superglue fuming chamber, as advised by CAST (Bleay, et al*.,* 2013), and therefore their results are not comparable to others.

In addition to this, an increase in polymer mass does not necessarily correspond to improved fingermark enhancement, as marks can become 'over developed' leading to a decrease in contrast between the latent mark and the background substrate (Bandey, et al*.,* 2014). The age of a fingermark also has a detrimental effect on the yield of polymer produced, which could prove an important factor when developing latent marks on painted walls at crime scenes (Yamashita and French, 2011; Bandey, et al., 2014). Researchers have suggested that the decrease in the quality of fingermarks could be due to the loss of aqueous components (Mong, Petersen and Clauss, 1999; Lewis, et al., 2001). Whereas Wargacki, et al., (2008) argue that it is the loss of initiators, such as carboxylic acids, that has a detrimental effect.

One of the issues facing superglue fuming is that the opaque polymers that adhere to the latent marks can be difficult to visualise (particularly on white substrates, such as white paint) as there is a distinct lack of contrast (Prete, et al*.,* 2013).Therefore, substrates that present such difficulties should be treated after being subjected to superglue fuming, to dye the polymer residues, thus making the contrast between fingermark and substrate much greater (Charlton, 2009; Jackson and Jackson, 2011).

The two staining methods that are advocated are basic yellow 40 and basic red 14, (Bandey, et al., 2014). One-step processes, such as Lumicyano™ (Crime Science Technology, 2016) and Polycyano (Foster and Freeman; 2016), have been studied, which combine both the superglue and the dye steps to produce fluorescent fingermarks; the results of which are comparable to the traditional two-step approach (Prete, et al*.,* 2013; Farrugia, et al., 2014a; Farrugia, et al., 2014b). However, such studies have only been carried out using fuming cabinets and therefore it is unclear whether or not this research would be applicable '*in situ'* at scenes.

The superglue technique can be difficult to utilise at crime scenes due to difficulties maintaining a steady humidity in addition to the dangerous vapour that is produced during the process, and therefore should only be used as a last resort (Home Office Scientific Development Branch, 2007). This can lead to significant respiratory difficulties and therefore procedures must be put into place to ensure adequate ventilation of the area once the fuming process has been completed (Charlton, 2009). However specific systems, such as SUPERfume (Foster and Freeman, 2015) have been designed to counteract these issues in order that the superglue fuming process is possible to carry out '*in situ'* (Fieldhouse, 2011a). This system would be ideal for superglue fuming the internal painted walls of a property, as the entire room could be treated simultaneously. Therefore, superglue fuming will be explored as part of this research. Nevertheless, the conditions of a scene cannot be fully controlled in comparison to a fuming cabinet; therefore, the results will not be of the same quality (Jackson and Jackson, 2011).

Conversely, powder suspension is a process that requires little equipment and can be applied to any surface. It involves applying a 'wet' powder to enhance fingermarks, although the precise mechanism of development is not yet understood (Bleay, et al., 2013). The general method involves mixing a fine powder (i.e. iron II/III oxide) with a concentrated detergent and wetting agent solution (i.e. Photo-Flo and water).

The combined solution is then applied to a wet surface using a brush, where the powder adheres to the ridges of the latent mark and the excess solution is washed away (Burns, 1994; Carlsson, 2003). This method has traditionally been used to develop marks on adhesive surfaces, such as tape, however more recently it has proven to be effective in developing marks on a range of non-porous and semi-porous surfaces (Bleay, et al., 2013; Bandey, et al., 2014). It is available as a dark or light solution, as the iron oxide II/III (for black powder suspension) can be replaced with titanium dioxide to create a white powder suspension. It can therefore be used on a range of coloured substrates, providing contrast between the fingermark and the background surface (Kent, 2013b). The ease of application and the possibility of distinguishing fingermarks on walls painted with a variety of colours makes this process ideal for using at scenes.

Whilst powder suspensions can be applied '*in situ*' at scenes, at present they are considered difficult due to '*clean up*' issues and are therefore primarily used in laboratories (Home Office Scientific Development Branch, 2007; Kent, 2013b). Another consideration influencing the efficacy of this process is the topography of the substrate involved, as even smooth non-porous surfaces vary in morphology, which subsequently affects the quality of fingermarks developed with powder suspension (Jones, et al., 2010). This is problematic for painted walls as the application of the paint will create an uneven surface (particularly if applied with a brush). This issue was observed by Lawrie (2007) who also noted that both silk and kitchen and bathroom paint appeared to be semi-porous due to the inability to rinse off the powder suspension and it being absorbed into the paint.

The use of this process is also known to interfere with other development processes and therefore cannot be used in sequence with other widely used techniques, such as superglue fuming (Scott, 2009). Also powder suspensions have shown inter- and intra-variability in developed marks from a range of donors, highlighting inconsistencies with the process; the reasons for this are not yet known (Stubbs, et al., 2015).

Nevertheless, powder suspension has been shown to be effective at developing latent fingermarks on modern variations of conventional substrates, such as plastic bags (Downham, et al., 2012; Farrugia, et al., 2014a). In these circumstances the composition of the item has changed due to advances in technology and environmental concerns and therefore long-established processes are now ineffectual (Downham, et al., 2012). This proposition could be transferable to this research, which focusses on modern architectural paint types where traditional development processes are also thought to be inadequate. Hence, powder suspension will be examined as part of this research.

1.5.2.2.2. Other Category A processes (Lifting, Small Particle Reagent & Solvent Black3)

Black gelatin lifters are primarily used by CSEs to lift and record latent fingermarks (and footwear marks) that have been developed using powders, however they can also be used to recover unprocessed marks, which is a relatively new concept (Bleay, et al*.,* 2011). A company, BVDA, have developed GLS^{can}, which produces high quality images of gel lifters which have been used to lift undeveloped latent marks direct from a substrate. It is both non-destructive to the fingermark and to the substrate itself and can therefore be used during covert operations (BVDA, 2012). However, the temperature of the surface to which the lifter is applied must be < 40 ^{o}C, otherwise the gelatin lifter may melt on the surface (Bleay, et al*.,* 2013). This could be problematic for painted walls at indoor scenes during the summer months, or at scenes involving hydroponics, where temperatures inside remain high (Bouchard, 2008). Another issue is the handling of used gelatin lifters, as these need to be imaged as soon as possible at the laboratory due to the degradation of lifted latent marks, and should be stored without a covering material (Bleay, et al., 2011; Bleay, et al., 2013). In addition to this, gelatin lifters do not perform as well as fingerprint powders on non-porous surfaces, and therefore are not recommended as the primary development process unless the targeted area is unsuitable for powdering, due to contamination or lack of space (Home Office Scientific Development Branch, 2007). Therefore, this process will not be investigated as part of this research.

Nevertheless, it would be beneficial to investigate the efficacy of gelatin lifters on painted walls, as part of a further research project (particularly for use in covert operations), to determine whether it is a viable process to develop latent fingermarks on different types of paints (noted in section 6.2.). As gelatin lifters are quick and easy to use, they could be employed by CSEs and FLOs alike at both volume and major crime scenes. It has already been established that gelatin lifters are an effective process on smooth, non-porous surfaces, such as gloss paint (Bleay, et al, 2017). However, as walls are primarily painted with matt paints (as discussed in section 1.1.3. and Figure 2), the surface of the walls will be more textured, and therefore gelatin lifters are likely to be more effective to recover marks developed with powders, rather than to recover untreated latent marks.

On the other hand, small particle reagent (SPR) can be lifted, as per fingerprint powders, and stored more easily. SPR consists of molybdenum disulphide particles within a detergent solution, which leaves a grey residue along the ridges (Sodhi and Kaur, 2012). It can be applied by submerging items or via a spray, which would make it ideal for use on painted walls at crime scenes. However, the spray method is not as successful as submersion in the solution, and therefore the application of this process should be fully considered prior to application (Charlton, 2009; Bandey, et al*.,* 2014).

Another development process that is affected by temperature is solvent black 3, which can only be used at crime scenes providing that the temperature does not exceed 48 ^{o}C due to the flammability of the solution (Charlton, 2009; Bandey, et al., 2014). This process (sometimes referred to as sudan black) is another treatment that can be used on non-porous substrates, targeting the fatty constituents found within latent marks, producing a black print (Kent, 2013b).

Whilst it can be used at scenes with a low temperature it is important to note that solvent black 3 can cause extensive background staining which is difficult to remove, due to its insolubility in water (Garrett and Bleay, 2013; Cadd, et al., 2013; Bandey, et al*.,* 2014). Therefore, careful consideration must be given prior to this technique being employed on painted walls at scenes and it should only be used when other processes are not possible. Therefore, this process will not be investigated as part of this research.

1.5.2.2.3. Category B processes (Europium Chelate, Natural Yellow 3)

Europium Chelate is useful as a fingermark development process due to its fluorescent properties caused by an increased Stoke's shift (Bleay, et al., 2013). The period of fluorescence is longer with europium chelate than with many other fluorescent processes, allowing more time for imaging. However, it is not recommended for general use due to its inability to produce quality ridge detail on fingermarks aged >24 hours (Ramotowski, 2013d). Therefore, whilst europium chelate could be applied to painted walls at crime scenes, the timeframe in which this process would be useful is unrealistic for casework, particularly as fluorescence examination is also required to visualise the marks. Thus, this process will not form part of this research.

Natural yellow 3 is another fluorescent fingermark development process that can be used on non-porous surfaces. It adheres to the fatty constituents present in latent fingermarks in a similar manner to solvent black 3. However, unlike solvent black 3, natural yellow 3 is a plant derivative, which has been synthesised from the roots of the turmeric plant and therefore can be utilised at scenes without any health and safety concerns (Daluz, 2015). Nevertheless, it is best used in sequence with solvent black 3, rather than as a single process, as natural yellow 3 has been found to enhance already processed marks, in addition to the development of other fingermarks (Perry and Sears, 2015). Therefore, as solvent black 3 will not be investigated during this study, natural yellow 3 will not form part of this research either.

1.5.2.3. Processes for semi-porous substrates (including silk and satin paint)

Despite new methods and applications being investigated, there are still some areas that rely on ‘trial and error’. This is particularly the case when examining semi-porous substrates where a combination of techniques for both porous and non-porous substrates is required (Sears, 2013). These must be carried out in a sequential order, as shown in Table 8, so that individual processes will not jeopardise the further examination of the item.

Table 8 - CAST recommended sequential processing of latent fingermarks on semi-porous surfaces
(adapted from Bandey, et al*.,* 2014)

Process	**In sequential order**	**CAST category**	**Ability to use on painted walls?**
Powders (Black Magnetic Granular)	1	A (Non-porous)	**Yes** – easy to apply on vertical surfaces
Vacuum Metal Deposition (VMD) (Gold/zinc)	2	A (Non-porous)	**No** – surface needs to be in vacuum
Superglue Fuming	2 (Followed by powders or VMD)	A (Non-porous)	**Yes** – specific equipment needed due to health and safety issues during processing
Powder Suspension	2 (Then, miss steps 3, 4 and straight to step 5)	A (Non-porous)	**Yes** – messy and difficult to clean-up
DFO (1,8-Diazafluoren-9-one)	3	A (Porous)	**Yes** – breathing apparatus required, reaction time varies according to environmental conditions, and requires fluorescence examination
Ninhydrin	4	A (Porous)	**Yes** – breathing apparatus is required, and reaction time varies according to environmental conditions
Physical Developer (followed by enhancement)	5	A (Porous)	**No** – requires submersion in three separate solutions

It can be seen that all of the techniques listed in Table 8 are also advocated in the processing guidelines for either porous or non-porous substrates; however, more specific details are provided for semi-porous substrates. For example, the non-porous chart has 'powders' listed as a technique, whereas the semi-porous guide specifically states that only black magnetic granular powders are likely to be reliable on these types of surfaces.

The issues that were discussed in sections 1.5.2.1. and 1.5.2.2 for porous (i.e. matt) and non-porous (i.e. gloss) paints also apply to semi-porous paints, such as silk and satin. This highlights a need for specific research into painted walls. Whilst some studies have sought to further knowledge in this area, these are limited in number, thus highlighting the importance of this research.

1.6. Review of research regarding fingermark processing of painted walls

At present there is limited fingermark research available regarding the enhancement of latent fingermarks on painted walls. Whilst the internal walls of a scene may not be routinely examined at volume crime scenes by CSEs, they are an integral part of the scene examination for major crimes by both CSEs and FLOs (as highlighted by practitioners in Chapter 2). The porosity of the surface will have an impact on the number of suitable development processes that may be used, (as discussed in sections 1.5.2.1, 1.5.2.2. and 1.5.2.3.), especially those that may be used '*in situ*' at scenes due to practicalities and/or health and safety concerns, in addition to ISO 17020 requirements (Bandey, et al*.,* 2014).

Iodine solution was the first development process that was recommended for use on painted walls (Pounds, et al., 1986; Pounds, et al., 1992; Pounds, 1989). This was subsequently replaced by ninhydrin, which achieved better overall results (Bleay, et al., 2013). However, due to the Montreal Protocol 1987, which banned the use of ozone-depleting chemicals, the formulation of both processes has been amended over the years (Velders, et al*.,* 2007), and therefore neither of these tested formulations can now be applied.

Recent research has compared contemporary formulations of both iodine (heptane-based) and ninhydrin, showing that iodine produced better results on painted surfaces (Fletcher, 2009). Therefore, iodine is worth exploring in more detail, and will form part of this study, although the health and safety issues surrounding the application of iodine at scenes must be taken into consideration.

In addition, Flynn, et al., (2004) explored whether iodine-benzoflavone (IB) and ruthenium tetroxide (RTX) would be useful processes in developing latent marks on painted walls, as these methods work well on both porous and non-porous substrates. Both techniques were applied using sprays and were compared against conventional black and white fingerprint powders using a squirrel hair brush (*ibid*). However, the authors did not specify the paint type/s used in this study, and therefore their methodology cannot be mirrored in this research. The results of the study showed that IB was only useful on marks aged <1 day and RTX on marks aged <3 days, thus highlighting that these processes are not useful for aged marks and will not be explored in this research (*ibid*). It is important to note the health and safety implications of using such processes at scenes, as RTX is considered extremely toxic. Home Office guidelines have classified it as a category F process, meaning that this technique has serious health and safety issues and should never be used in an uncontrollable environment such as a crime scene (Bandey, et al*.,* 2014). Therefore, RTX will not be explored in this research.

Lawrie (2007) explored the use of powder suspension to develop latent fingermarks on silk, and kitchen and bathroom painted substrates. The research found both paint types behaved in a similar manner to semi-porous substrates, due to the absorption of powder suspension into the surfaces, preventing it from being rinsed off to provide contrast between the mark and the background.

Lawrence, et al*.,* (2010), expanded upon this study, using ninhydrin, powder suspension and a combination of the two techniques (ninhydrin followed by powder suspension) on eight different paint types (including matt, kitchen matt, silk, gloss and satin). A higher percentage of identifiable fingermarks were obtained using powder suspension, compared to ninhydrin. These findings contradict previous ideology that porous treatments, such as ninhydrin (in conjunction with lighting methods) were the best methods to develop fingermarks on matt painted walls (Police Scientific Development Branch, 1998). This has subsequently been updated and reflected in Home Office guidelines for practitioners (Bandey, et al*.,* 2014), and will be explored in detail in this study.

Gelatin lifters have also been tested on silk painted walls, but with limited success (Bleay, et al., 2011; Bleay, et al., 2013). The effectiveness of gelatin lifters diminished as the porosity and texture of the substrate increased, highlighting that whilst this process is mess-free it is not a suitable technique to use on more porous/textured paints (*ibid*). Therefore, it was not investigated in this research.

More recently Nakamura, et al*.,* (2015) conducted further research into the use of light sources and a hyperspectral imager to detect untreated latent marks on walls '*in situ*' at crime scenes. The hyperspectral imager provided the best results when coupled with a green laser (532 nm); the data from which could even distinguish between prints that were overlaid (*ibid*). However, the types of wall used in this study (steel wall with a polythene resin) are not likely to be encountered in the UK, as most internal walls consist of plaster/plasterboard and are painted (Barry, 1999; Emmitt and Gorse, 2014).

As this chapter has highlighted, there is a plethora of research exploring general fingermark development processes. However, there is only limited information available regarding the development of latent fingermarks on painted walls. This lack of research makes it difficult to produce accurate guidelines for practitioners, which needs to be based on validated data. Nevertheless, this chapter has shown that there are a large number of techniques that can be used to develop and enhance latent fingermarks. However, many of these are laboratory-based processes that are difficult or impossible to conduct '*in situ*' at crime scenes (i.e. vacuum metal deposition). Therefore, this study aims to fill the gap in knowledge by providing necessary information and data to practitioners, so that they are able to make informed choices at scenes. This research will examine the effectiveness of ninhydrin, indandione, iodine solution, silver nitrate, black magnetic granular powder, magneta flake powder, superglue fuming (with BY40 dye), and powder suspension to develop latent fingermarks on painted walls.

1.7. Aims and objectives of this study

This chapter has highlighted the issues surrounding the use of fingermark development processes at crime scenes, emphasising a gap in knowledge regarding the development of fingermarks on painted walls '*in situ*'. Due to this lack of research, at present the efficacy of processes in developing latent marks on walls that have been coated with modern paints is unclear.

Consequently, it is vital that research is carried out in order that practitioners can apply the most effective processes (in the correct sequential order) to maximise the yield of fingermarks that can be obtained from scenes involving painted walls. Therefore, the aim of this study is to determine which fingermark development processes are most efficient at developing latent marks on walls that have been painted.

In order to achieve this aim, the following objectives have been set:

1. Ascertain the current methods used by practitioners in the field to develop fingermarks on painted walls, and why these are used (explored in Chapter 2).
2. Determine whether or not variations of paint types and brands have an effect on deposited fingermarks from different donors (explored in Chapter 2).
3. Establish the primary differences between different paint types, using microscopic techniques (including Scanning Electron Microscopy), allowing them to be categorised into coherent groups (explored in Chapter 3).
4. Investigate which processes are most effective at developing fingermarks on different paint types (explored in Chapter 4).
5. Propose new guidelines for practitioners, detailing efficient sequential processes for the different paint types (explored in Chapter 5).

Chapter 2 – Establishing the effectiveness of current fingermark development processes

2.1. Introduction

This chapter is composed of a practitioner survey followed by three separate sets of experiments. The survey was conducted to ascertain the current methodologies being used by practitioners working in the field throughout England. The results of this survey then informed the design of the preliminary experimental work, which included testing whether or not the wall finish (i.e. plaster, plasterboard), the paint type used (i.e. matt, silk), and the brand of the paint (i.e. Dulux, B&Q) would have an effect on the most commonly used fingermark development processes.

The aim of this first experimental chapter was to determine the efficiency of the most commonly used fingermark development processes on painted walls (according to the data collected from practitioners), and whether or not variations of paint types have an effect on the development of latent fingermarks. Previous studies have explored a range of development processes, on differing paints (Flynn, et al*.,* 2004; Lawrie, 2007; Fletcher, 2009; Lawrence, et al., 2010) and guidelines have been provided by the Home Office (Bandey, et al*.,* 2014). However, the guidelines were prepared using data collated from studies involving older style paints and therefore it is unclear whether these can effectively be applied to contemporary paints. The specific changes in paint composition is unclear, as the unique composition of each paint type/brand is (and has always been) securely held by manufacturers owing to patents. Thus, other than changes in legislation, such as lowering VOC levels and the removal of lead, it is unclear as to what these changes may be. In addition to this, the techniques being used by practitioners at crime scenes do not always correspond with the Home Office guidelines, which will have an impact on ISO 17020 accreditation. Therefore, this research aims to not only fill this gap in knowledge, but also to provide updated guidelines for practitioners, based on current research. It is hoped that by providing scientific evidence to practitioners it will assist them in understanding why the new updated guidelines should be adhered to.

2.2. Practitioner survey

2.2.1. Method

Due to the lack of published research regarding latent fingermarks on painted walls, it was necessary to gain the perspectives of fingermark development practitioners to ascertain precisely which processes are currently being used in the field and why. Therefore, an online anonymous survey was designed as part of this research to gain an insight into the current practices employed (Iarossi, 2006). A total of 17 questions were posed to practitioners (Table 9), which involved respondents answering a range of closed, scaled and open questions (see Appendix 1). The chosen questions allowed for both qualitative and quantitative data to be collected, which can increase the validity and confidence of any findings (Buchanan and Hooper, 2005). Whilst the survey was anonymous, the questions requested information such as '*role'*, '*length of service'* and '*police service'* to ascertain if there was any correlation between the answers provided and geographical location, or experience.

The questionnaire was distributed (via a 'surveymonkey' web link) to practitioners with a working knowledge of fingermark development '*in situ*', such as Crime Scene Examiners (CSEs - who attend all types of crime scenes on a daily basis), Crime Scene Managers (CSMs – who are experienced CSEs, but generally only attend/manage major crime scenes) and Fingerprint Laboratory Officers (FLOs - who only attend major crimes scenes, as they are primarily based in a laboratory). Fingerprint Examiners, however, were not invited to take part in the questionnaire, as they only handle post-developed marks and are not involved in the development of latent fingermarks (Earwaker, et al*.,* 2015). Scientific Support Managers were also contacted enabling them to disseminate the link to the appropriate practitioners within their Police Service. The online questionnaire opened in May 2015 and closed in December 2015; the responses (N=92) were subsequently analysed in order that the findings could be applied to the experimental work. A total of 18 Police Services in England took part in the research, providing a geographical spread across the country and representative mix of smaller county Police Services and larger Metropolitan Police Services.

Table 9 - List of questions posed to fingermark development practitioners

Order	Question asked
1	Which Police Service are you employed by?
2	What is your current position?
3	How long have you worked in your current role?
4	How often do you attend crime scenes?
5	What type of crime scene might you be called to attend?
6	What is your main role at a crime scene?
7	What would normally be your method of choice in developing fingermarks '*in situ*' at the following crime scenes? (different scene types are listed in Appendix 1)
8	At what type of crime scene would you normally consider examining the walls of the scene for fingermarks?
9	How often would you estimate that you examine the walls of a crime scene for fingermarks?
10	Does the type of paint used on the walls have any effect on the decisions you make as to which development technique you will use?
11	On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on MATT painted walls at crime scenes? (techniques are listed in Appendix 1)
12	On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on SILK painted walls at crime scenes? (techniques are listed in Appendix 1)
13	On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on KITCHEN / BATHROOM painted walls at crime scenes? (techniques are listed in Appendix 1)
14	What would be your preferred method of gaining fingermarks from walls and why?
15	How much of a wall would you examine?
16	What do you think are the main issues preventing examiners from gaining more fingermarks from walls?
17	Is there a need for something to be developed to assist examiners in gaining more fingermarks from walls?

A pilot study was conducted with a small number of CSEs prior to the questionnaire being distributed in order to highlight any ambiguous questions and identify anything that could prevent practitioners from completing the questionnaire (Jones, Baxter and Khanduja, 2013). Minor amendments were made accordingly and the questionnaire was released to fingermark practitioners; the data from which was then collated and analysed.

Despite a pilot study having taken place, there are limitations to any method of surveying, which need to be recognised. The use of an online questionnaire is impersonal, and anonymous, allowing respondents to answer honestly without fear of any reprisal (Wright, 2005). However, it also means that the questions only allow for a limited depth of response and prevents any further questions based on the response given, meaning that clarification and elaboration of answers was not possible.

In addition to this, whilst the target population was clearly stated in the participant information (i.e. CSEs, FLOs), other personnel from Police Services attempted to complete the questionnaire. Also, some participants only partially completed the questionnaire, leaving many questions unanswered. Both of these types of responses were disregarded and not analysed, and are therefore not reported in this thesis. Only completed questionnaires from relevant fingermark practitioners were included in the reported data.

Another limitation to the survey methodology is the use of online software. In order to disseminate the questionnaire, practitioners often forwarded the link to colleagues both within their own Police Service and in other Police Services within England. Online firewalls and virus guards differ in each Police Service, and some do not allow weblinks to be emailed to employees. Therefore, some Police Services, such as the Metropolitan Police, could not participate due to being unable to access the web link, thus limiting the number of total participants (Wright, 2005).

2.2.2. Results and discussion

The primary purpose of the survey was to ascertain what methods are currently being used to develop latent fingermarks on painted walls at crime scenes and why. From the data collected, it was possible to identify key themes (outlined in section 2.2.2.2.), which would inform the experimental design of the preliminary studies (section 2.3.2).

2.2.2.1. Geographical distribution of participants and role

The practitioners that responded to the survey had differing roles (i.e. Crime Scene Examiner, Fingerprint Laboratory Officer), which may have influenced their answers, and therefore the distribution of each role across the 18 Police Services was determined (Figure 9).

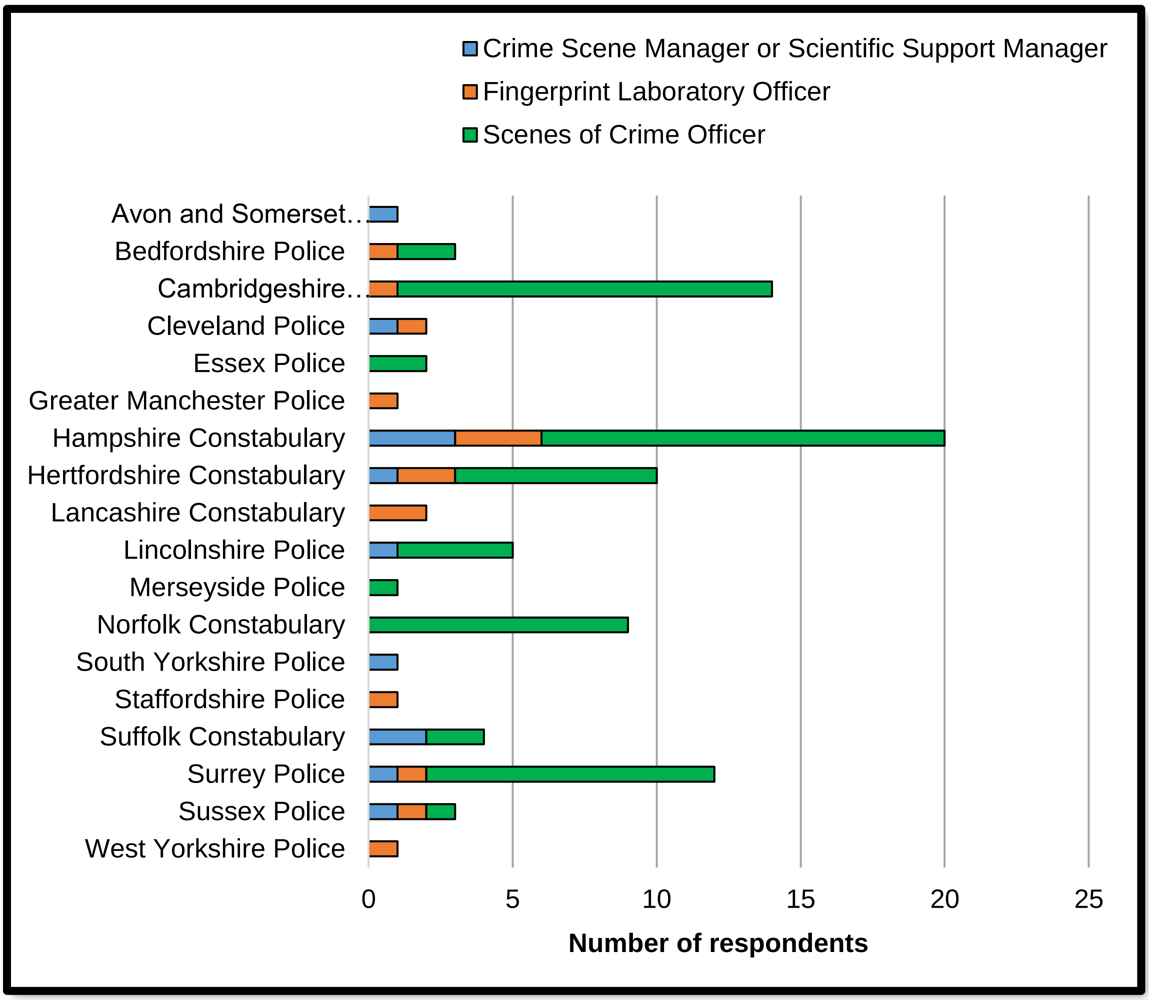


Figure 9 - Geographical distribution of participants (N=92) according to their role

In total, 92 responses were recorded; the majority (70%) of which were Scenes of Crime Officers (also known as Crime Scene Examiners), followed by Fingerprint Laboratory Officers (17%) and Crime Scene Managers (13%), which is representative of those employed in England.

2.2.2.2. Consideration of painted walls at crime scenes

The results of the survey showed that CSEs attend more crime scenes each year (all on a daily basis) compared to CSMs who had an average attendance of one crime scene per month, and FLOs who had an average attendance of one crime scene every 3 to 6 months. This is due to CSEs attending scenes of all crime types, from volume crimes (i.e. burglary and criminal damage) to serious crimes (i.e. sexual offences and suspicious death) as shown in the survey results. CSEs should follow standard operating procedures when developing latent fingermarks (in accordance with ISO 17020 standards). FLOs on the other hand only attend more serious crime types (arson, violence against person, sexual offences and suspicious deaths), which occur less frequently, thus they attend less scenes. FLOs will follow standard operating procedures that are designed for laboratories (in accordance with ISO 17025 standards) and also standard operating procedures that are designed to be used '*in situ*' (in accordance with ISO 17020 standards).

All of the practitioners were also asked specifically about the examination of walls '*in situ*' at crime scenes. They were requested to identify in which types of crime scenes they would consider examining the walls and what development processes they would prefer to use in such circumstances. The results show that the likelihood of walls being examined at scenes increases with the severity of the crime, as shown in Table 10. This result was expected as more resources are employed for serious crimes, such as murder, compared to volume crimes, such a burglary, which are a common occurrence (Kent, 2013a).

Table 10 - The likelihood of walls being examined at differing types of crime scenes

Crime Type	**Likelihood of walls being examined (%)**
Car crime	3.45
Criminal damage	24.14
Burglary	48.28
Armed robbery and ram raids	42.53
Arson	45.98
Violence against person	65.52
Sexual offences	70.11
Suspicious death	87.35

The fingermark development processes used by practitioners on walls at crime scenes varied according to their role, with CSEs using powders, and FLOs using optical and physical/chemical methods. Their choices are aligned with their role and the training that they have received, for example CSEs are primarily trained to use powders, whereas FLOs are trained to use other methods (as shown in Figure 10). This ratio of practitioners (i.e. CSEs – 70% vs. FLOs – 17%) may skew some of the results in the survey, as CSEs will primarily use powders at scenes (Bandey and Gibson, 2006), and therefore may not have recommended the use of other processes, whereas FLOs may have responded differently due to their extended knowledge of fingermark development processes.

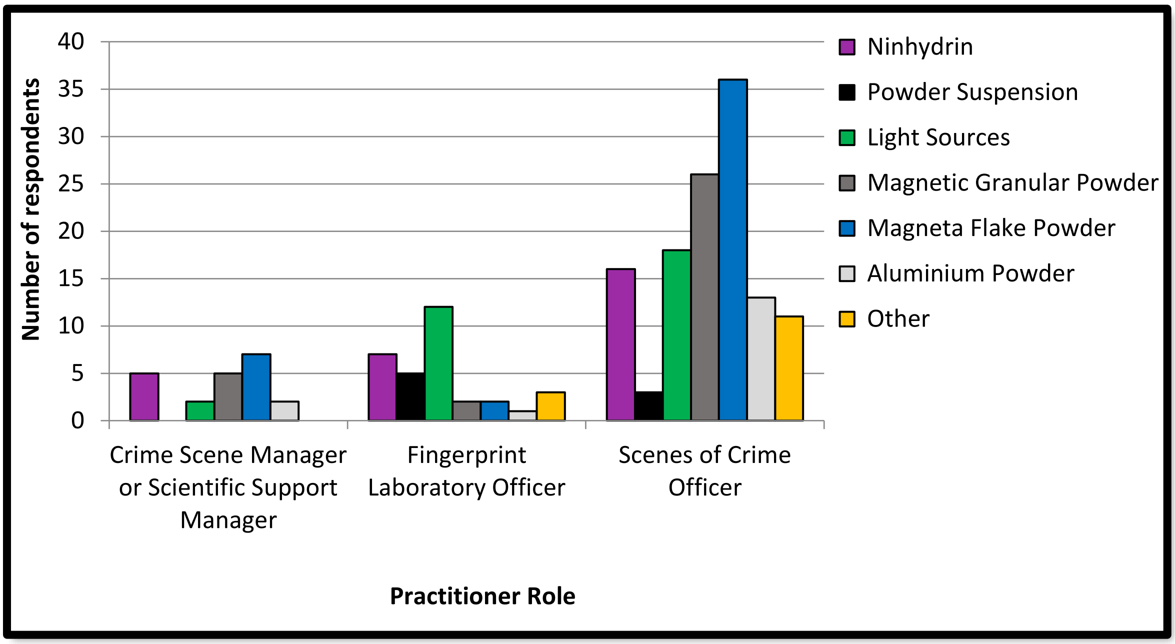


Figure 10 - Frequency of development processes used to develop latent fingermarks on walls according to their role

Magneta flake powder proved to be the most popular development method with 49% of respondents stating that they would use this on walls of crime scenes; the majority of which were CSEs and CSMs. This was followed by black magnetic granular powder (36%), light sources (35%) and ninhydrin (30%). The preference for magneta flake powder contradicts the Home Office guidelines, which does not recommend the use of this powder on any type of painted wall (Bandey, et al., 2014). The only powder recommended for use on walls is black magnetic granular powder, and only on silk painted walls (*ibid*). The Home Office guidelines do recommend the use of light sources, ninhydrin and powder suspension on all wall types; however, in reality powder suspension is seldom being used, as highlighted in Figure 10.

The respondents were also asked if the type of paint found on the walls of a crime scene would affect their choice of development process. The majority of practitioners (64%) stated the type of paint used on the wall would have an effect, with 23% stating that it would sometimes affect their decisions and 13% saying that the paint type would never affect their choice of development process.

When asked to elaborate on how they would ascertain what paint type had been used and therefore which process to use, four main themes were identified and have been summarised using the following quotes:

> **Theme 1 - Trial and error -** "*assessment of the surface then spot testing the area to see if background staining is going to be an issue*"
>
> **Theme 2 – Visual examination** - "*I would assess the paint visually and select a powder based on texture and colour*"
>
> **Theme 3 - Seek confirmation** – "*Ask aggrieved*"
>
> **Theme 4 – Practitioner knowledge** - "*Past experience*"

Only one practitioner mentioned that they would consult Home Office guidelines, thus highlighting that Police Services should expand the training for fingermark development personnel, particularly CSEs/CSMs who may not be as familiar with the Fingermark Visualisation Manual compared to FLOs (Bandey, et al*.,* 2014). It is important to note that the survey was undertaken prior to ISO accreditation being a requirement for most practitioners. It is suggested that this issue may be significantly reduced once all practitioners are accredited to either ISO 17020 or ISO 17025 standards, as once accredited they will all have to follow standard operating procedures.

2.2.2.3. The future of development processes for painted walls

The final question posed to practitioners was whether or not they felt the need for something to be developed to assist in the enhancement of fingermarks on painted walls, and if so, what they would find useful. A minority of participants (20%) did not feel that there was a need for something new to be developed stating that "*Techniques are available and used in the right circumstances when it can be justified*". However, the majority of participants (80%) felt that there was a need for something to be developed.

Some suggestions from practitioners were "*A non-toxic spray on chemical that causes minimal mess*", "*Use of spray for scene examiners instead of chemical lab staff at major scenes",* "*A powder that works better on walls, that can be carried by CSEs that is easy to apply and clean off*", and "*a non-damaging powder or suspension that we can treat the walls with*". Another respondent also commented "*research/ trials/ dissemination of results in 'real' scenes not just lab conditions*", highlighting the importance of using realistic materials to mimic conditions found in 'real' scenes rather than controlled laboratory conditions.

2.2.2.4. Limitations of the survey

The survey provided in depth data from fingermark practitioners across England, which complemented and contrasted the published literature discussed in Chapter 1. Nevertheless, there are limitations with the methodology chosen for the survey, which potentially affected the results. Firstly, the use of a questionnaire to gain information from practitioners will limit the amount of detailed information that can be gained from each individual. Whilst the use of open-ended questions allows for participants to add further details where necessary, these may be written in ambiguous terms or could have been expanded upon further during a conversation (Saris and Gallhofer, 2014). Secondly it was not possible to get a representative sample of fingermark practitioners from each force across the country due to the use of an online survey. Some Police Services have additional firewalls that block emails with web links or attachments, thus preventing personnel from those Police Services from completing and further distributing the survey to others.

2.2.2.5. Conclusions from the survey

Regardless of the limitations, the data gained from the survey provided a necessary insight into the thought processes of fingermark development practitioners and the current development processes used '*in situ*' at crime scenes. The survey identified the three most commonly used development processes on painted walls, which were black magnetic granular powder (non-porous process), magneta flake powder (non-porous process), and ninhydrin (porous process). These processes were therefore used in the preliminary experimental work of this study (section 2.3.2) to ascertain their efficacy on painted walls.

2.3. Materials and methods for preliminary experimental work

The information gained from the practitioner survey was used to inform the methodology of the preliminary experimental work. The aim of this pilot study was to ascertain whether or not the wall finish (i.e. plaster, plasterboard), the paint type (i.e. matt, silk) or paint brand (i.e. Dulux, Wickes) had an effect on the development of fingermarks. These variables were tested in three separate experiments (section 2.4.1, section 2.4.2. and section 2.4.3.)

2.3.1. Materials

Knauf plasterboard, Knauf Drywall Easy plaster, Medium-coarse sanding paper, Wickes (ready mixed) plasterboard sealer, Paint brushes (1 inch - synthetic bristles), Medium-pile mini rollers, Wickes Trade Flat Matt (White), Wickes Trade Vinyl Silk (White), Wickes ‘Colour at Home’ Bathroom (White), Wickes Trade Eggshell (White) were purchased from Wickes, UK; Homebase Value Vinyl Matt (Brilliant White), Homebase Kitchen and Bathroom Matt (Brilliant White), Homebase ‘Home of Colour’ Duracoat (Soothing White), Homebase ‘Home of Colour’ Kitchen and Bathroom (Soothing White), Homebase Silk (Brilliant White) were all purchased from Homebase, UK; B&Q ‘Colours’ Matt (Magnolia) was purchased from B&Q, UK; Dulux Matt (Pebble Shore), Dulux Matt (Polished Pebble), Dulux Silk (Almost Oyster) were purchased from Dulux, UK; acetic acid (CAS-64-19-7: HPLC Grade), ethanol (CAS-64-17-5: HPLC Grade), ethyl acetate (CAS-141-78-6: HPLC Grade) were all purchased from Fisher Scientific, UK; ninhydrin ACS reagent (CAS-485-47-2) was purchased from Sigma Aldrich, Germany; 1-methoxynonaffluorobutane (HFE7100) was purchased from 3M Novec, USA; squirrel hair brush (92-15), magnetic wands (PW/259), linen glass were purchased from WA Products, UK; magneta flake powder (96567) was purchased from Crime Scene Investigation Equipment, UK; magnetic granular powder (Jet Black) (TFP0105) was purchased from Tetra Scenes of Crime Ltd, UK; Nikon D90 camera was purchased from Nikon UK Ltd, UK; amino acid reference pads, sebaceous reference pads were purchased from Lightning Powder, USA.

2.3.2 Methods

2.3.2.1. Preparation and application of development processes

Three development processes were utilised in all of the preliminary experiments; ninhydrin, magneta flake powder and black magnetic granular powder.

2.3.2.1.1. Ninhydrin

The ninhydrin solution was prepared in accordance with the Home Office Fingermark Visualisation Manual (Bandey, et al., 2014). 25 g of ninhydrin was combined with 25 ml acetic acid, 225 ml ethanol and 10 ml ethyl acetate to produce a concentrated ninhydrin solution. The ninhydrin working solution was then obtained by combining 52 ml of the concentrated solution with 1 L of HFE7100, which was stored at room temperature ready for use. The ninhydrin was applied to the substrates using a soft squirrel hair brush (in order to mimic how it would be applied '*in situ*' at scenes) until the whole area had been covered. Once treated with ninhydrin, the simulated walls were assessed and marks graded on three separate occasions (3 days, 10 days and 17 days post-treatment) due to the uncertainty of the optimum time that ninhydrin should be left to react with the amino acids present in the latent fingermarks.

2.3.2.1.2. Magneta Flake Powder

The magneta flake powder was applied to the substrates with a magnetic wand using a methodical sweeping motion to ensure that all of the surface area had been in contact with the powder.

2.3.2.1.3. Black Magnetic Granular Powder

The black magnetic granular powder was applied to the substrates, as described in section 2.3.2.1.2.

2.3.2.2. Methods used to determine the effect of wall finish

Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (200 x 300 mm) to provide simulated walls (N=27). Some of the boards (n=9) had a layer of Knauf Drywall Easy Plaster applied, which was subsequently sanded by hand using medium coarse sanding paper to provide the smooth finish associated with plastered finished walls. Plasterboard Sealer was applied to some boards (n=9) to simulate sealed yet unplastered walls, and the remaining boards (n=9) were left bare to simulate untreated plasterboard walls. Each board was sectioned into quarters using masking tape, with a different paint type applied to each section. The four different paint types used in this study (Table 11) were reported to be the most frequently purchased by consumers in the UK (Wickes, 2015) and represent a range of porosities from matt (porous) to eggshell (non-porous).

Paints were applied using a medium pile mini roller to provide an even layer of paint to the boards. Each board received 3 coats of the same paint, with the designated time left between coats as prescribed on the tins. After 1 week, fingermarks (n=14) were deposited by the researcher onto each section of the board. Hands were washed prior to deposition, followed by each finger being loaded with residue from either an amino acid reference pad (n=7), or sebaceous reference pad (n=7). The total number of marks deposited for this experiment were 1,512 (56 fingermarks on 27 boards), allowing for each test to be carried out in triplicate.

Table 11 - Paint types used in experimental work

Paint Type	Paint Brand
Matt	Wickes Trade Flat Matt (White)
Silk	Wickes Trade Vinyl Silk (White)
Bathroom	Wickes ‘Colour at Home’ Bathroom (White)
Eggshell	Wickes Trade Eggshell (White)

2.3.2.3 Methods used to determine the effect of paint type

Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (200 x 300 mm) to provide simulated walls (N=72). Each board had only one paint type (Table 11) applied using a medium pile mini roller to provide an even layer of paint to the boards.

Each board received 3 coats of the same paint, with the designated time left between coats as prescribed on the tins. After 1 week, the boards were divided into 30 sections and 30 donors (of mixed gender, age and ethnicity) were recruited to donate one fingermark per board, using the same section on each board to allow for direct comparisons, as shown in Figure 11. Donors were given a set of instructions as outlined in Table 12 and started their depositions on different boards to gain an even distribution of residue levels. The total number of marks deposited for this experiment was 2,160 (30 fingermarks on 72 boards).

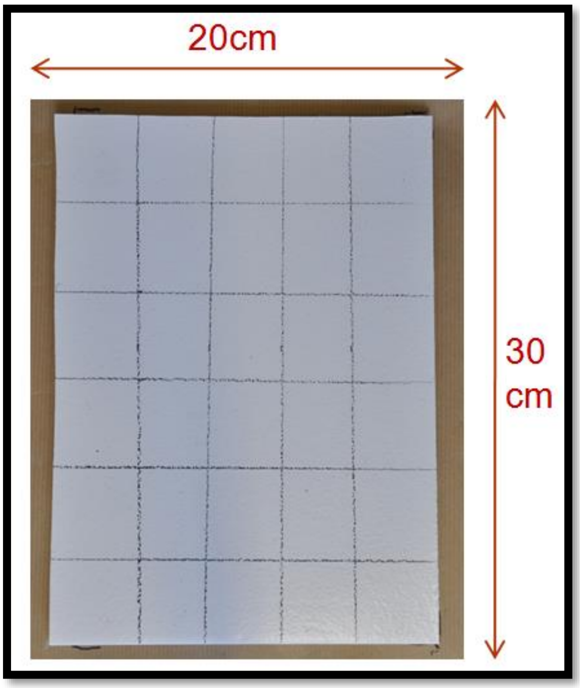


Figure 11 - Image showing board having been divided in 30 sections

Table 12 - Instructions provided to donors prior to deposition

Step	Description
1	Donor asked to read through Participant Information Form
2	If happy, donor signs Participant Consent Form (1 copy provided to donor, 1 copy kept by researcher)
3	Demonstration provided on donating a fingermark a) Gently touch the surface – do not press down hard b) Finger should touch surface and then be removed upwards – do not roll finger from side to side
4	Donors asked to rub hands together well to distribute natural residues.
5	Explanation provided about only one digit being used on each board – starting with thumb on first board, followed by forefinger on next board, and so on, until all ten digits were used. Then hands should be rubbed together again and the process can start again on the next 10 boards.
6	Donor allocated a box on the board (i.e. second row down, second box from the left) and the importance of only touching that box was emphasised.
7	Researcher points to allocated box on the first board and asks donor to leave their mark, and then moves to the next board and repeats the process until all the boards have been touched

2.3.2.4. Methods used to determine effect of paint brands

The purpose of these experiments was to determine whether or not different brands of matt and non-matt paint had an effect on the fingermark development processes used. Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (150 x 200 mm) to provide simulated walls (N=36). Each board was sectioned into 6 vertical strips using masking tape, with each section having two coats of paint applied (Table 13). Each of these paints were applied using a synthetic paint brush due to the small surface area being covered. After a week, the board was sectioned horizontally into four and fingermarks (n=8) were deposited by the researcher onto each strip within each section of the board, using loaded marks from either an amino acid reference pad, or sebaceous reference pad. The total number of marks deposited for this experiment was 1,728 (48 fingermarks on 36 boards).

Table 13 - Different brands of paints used in experimental work

Paint Type	Paint Brand
Matt	Homebase Value Vinyl Matt (Brilliant White)
	Wickes Trade Flat Matt
	B&Q 'Colours' Matt (Magnolia)
	Dulux Matt (Pebble Shore)
	Dulux Matt (Polished Pebble)
	Homebase Kitchen and Bathroom Matt (Brilliant White)
Non-Matt	Homebase 'Home of Colour' Kitchen and Bathroom (Soothing White)
	Homebase Silk (Brilliant White)
	Wickes Trade Vinyl Silk
	Dulux Silk (Almost Oyster)
	Wickes Trade Eggshell
	Homebase 'Home of Colour' Duracoat (Soothing White)

2.3.2.5. Timing of fingermark development

To ascertain whether or not the time between deposition and development of fingermarks had an impact on results, a set of boards were developed a day, a week and a month after deposition to imitate the realistic time frame in which a crime scene would be examined. All boards were left in general room conditions (average temperature 18^{o}C and relative humidity 45%) throughout the experiment to mimic the conditions commonly found with indoor crime scenes, with fluctuations in natural light occurring through an adjacent window.

In order to ensure that the age of the paint did not affect the results of this research (particularly regarding background staining), a pilot study was conducted over a 12 month period to assess the interactions of paint and fingerprint powders over time. The results showed that there were no differences in the interactions of powders on the 4 main paint types (listed in Table 11) between 1 week to 12 months. This proves that the age of the paint does not have a significant effect on the development of fingermarks with powders.

2.3.2.6. Visualisation and recording of developed marks

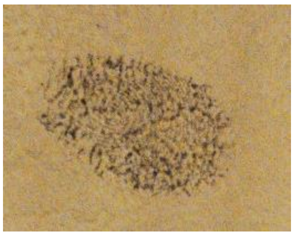
Boards were immediately photographed prior to grading using a Nikon D90 camera. All fingermarks developed during the experiments were individually viewed using a linen glass and the quality of fingermark ridge detail developed was graded using the adaptable Home Office scale of 0-4, as shown in

Table 14 (Bandey, 2004; Sears, et al., 2012; International Fingerprint Research Group, 2014).

2.3.2.7. Statistical analysis

All grades were stored electronically in a spreadsheet format (both in Microsoft Excel and IBM SPSS) to enable subsequent statistical analysis of the data collected. Each set of results were assessed to determine whether the data was parametric or non-parametric (see Appendix 2 for an example), and the appropriate statistical tests were then applied to analyse the results. All of the data collected in this chapter was non-parametric and therefore the Mann-Whitney U test (comparing two means) and the Kruskal-Wallis test (comparing more than two means) were utilised to ascertain whether or not the results were statistically significant at 95% confidence level.

Table 14 - Fingermark grading system used in this study
(adapted from Sears, et al., 2012)

Grade	Description	Image	Likelihood of identification
0	Nothing visible		None
1	Partial fingermark visible but little/no ridge detail		None
2	1/3 of the fingermark visible with ridge detail		Limited
3	2/3 of the fingermark visible with ridge detail		Moderately strong
4	Full fingermark with ridge detail		Very strong

2.4. Results and discussion for experimental work

2.4.1. Effect of wall finish

The purpose of these experiments was to ascertain if the finish of the wall had an effect on the fingermark development processes used. It is widely accepted that the topography and porosity of substrates has an effect on the deposition and development of latent fingermarks (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al*.,* 2014), and therefore it is important to assess whether or not the wall finish (i.e. plaster, sealed plasterboard and plasterboard) has an effect.

In total, 1512 fingermarks were analysed and graded (Table 15) according to the scale described in Table 14; with 504 fingermarks deposited on each wall finish type. The results for the total number of fingermarks developed (grade 1 to 4) in this experiment only show a small difference (11 fingermarks, or 2%) between plaster (the worst performing wall finish) and sealed plasterboard (best performing wall finish).

Table 15 - Total number of fingermarks developed according to wall finish (plaster, plasterboard, and sealed plasterboard) (N=1512)

Wall Finish (n=504)	**Number of fingermarks developed (grade 1 to 4)**	**Number of quality fingermarks developed (grade 3 or 4)**
Plaster	154 (31%)	23 (5%)
Plasterboard	161 (32%)	26 (5%)
Sealed Plasterboard	165 (33%)	25 (5%)

The results for each wall finish showed a skewed distribution (an example of a skewed distribution is presented in Appendix 2) and therefore the non-parametric Mann Whitney U and Kruskal-Wallis statistical tests were applied. The results for the Kruskal-Wallis test returned a p value of 0.75 at a 95% confidence level. As the p value is greater than 0.05, the test confirms that there was no significant difference in the wall finishes tested in this experiment. The poorer fingermark results (154 marks) obtained from the plastered wall finish may be due to the topography of the wall, as discussed in Chapter 3 (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014). A professional plasterer was not used in this research and therefore the texture of the plaster may not have been as smooth as that normally found on a wall in a property, despite having also been sanded. Nevertheless, there were minimal differences in the development of latent fingermarks between the wall finishes. Therefore, this need not be considered in detail when developing fingermark evidence recovery plans using standard operating procedures (as per ISO 17020 and 17025 requirements), as it will not have an effect on the quality/quantity of marks developed.

Whilst sanding only removes prominent ridges on a surface, additional indentations are also created (Arnold, 2010). This may affect the deposition of fingermarks, as surface texture is known to have an impact on the deposition of fingermarks, affecting the overall clarity of the developed mark (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014). However, the differences in overall results are not statistically significant as shown by the Kruskal-Wallis test (p value: 0.75). These results highlight that the overall wall finish does not have an impact on the quality and quantity of fingermarks developed. However, it is necessary to explore all variables (such as paint type and development process) within this experiment to ascertain whether or not there may be exceptions to these overall findings.

2.4.1.1. Effect of wall finish and paint type

The relationship between wall finish and porosity of the paint may also have an effect on deposited fingermarks. Direct comparisons were made between the four paint types used (matt, silk, bathroom, eggshell) for this experiment on plaster, plasterboard and sealed plasterboard (Figure 12).

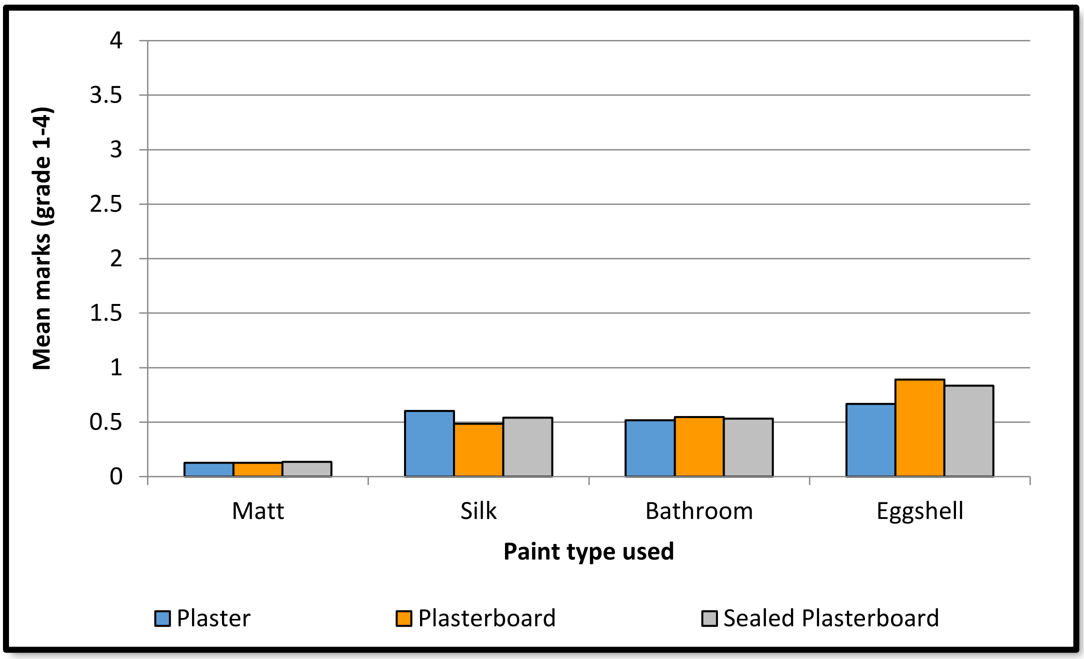


Figure 12 - Chart comparing effect of wall finish (plaster, plasterboard and sealed plasterboard) on paint types (matt, silk, bathroom and eggshell)

As Figure 12 shows, the results for matt and bathroom paint were consistent, with a difference of 0.002% for matt paint and a difference of 0.01% for bathroom paint between all wall finishes. The results for silk and eggshell paint showed more variation, particularly between plaster and plasterboard, and therefore the Mann Whitney U test was applied to analyse wall finishes and paint types together to determine whether or not these differences on silk and eggshell paint were significant. For silk paint applied to plaster and plasterboard the test returned a p value of 0.38, which was not significant. For eggshell paint that was applied to plaster and plasterboard the test returned a p value of 0.13, which was also not significant. Therefore, the results confirm that the wall finish does not have a significant effect on the development of fingermarks deposited on different paint types.

The results (Figure 12) for the most porous paint type (i.e. matt) are consistent with published literature regarding the protection of fingermarks due to absorption (Kent, 2013a; Bandey, et al., 2014), showing little difference in results on all wall finishes. Baurmann, et al*.,* (2013) state that the finish of the internal wall can have an effect on airflow and therefore many domestic houses have a layer of plaster applied to make the wall 'airtight'. However, the internal walls of some modern houses consist solely of plasterboard (without a layer of plaster), which may have an effect on airflow (Barry, 1999; Emmitt and Gorse, 2014). This would subsequently have an effect on deposited fingermarks as increased airflow causes latent fingermarks to age more rapidly, particularly on non-porous surfaces (Bandey, et al., 2014). Therefore, if the wall was not 'airtight', the fingermarks deposited on non-porous paints (i.e. eggshell) would not be expected to persist as long as those deposited on more porous paints (i.e. matt). This is due to the fingermarks being '*protected*' once absorbed into the more porous paints, whereas the marks remain on the surface for non-porous paints (Kent, 2013a).

However, the issue of airflow could not be fully tested in this research due to the use of simulated walls, rather than actual walls. Conversely, similar results were noted with bathroom paint (which produces a more non-porous finish to the wall), thus highlighting that in this study there is no correlation between the overall finish of the wall and the porosity of the paint. It is necessary to take into account that simulated walls were used for these experiments, rather than actual walls, and therefore additional research would need to be conducted to fully prove this point. In addition to the numerical data collected, qualitative information was also recorded throughout the experiments, which noted the issue of background staining. This was consistent on all wall finishes, but varied according to paint type (as discussed later in section 2.4.2.1.).

2.4.1.2. Effect of wall finish and development processes

The efficiency of fingermark development processes (magneta flake powder, black magnetic granular powder and ninhydrin) on different wall finishes (plaster, sealed plasterboard and plasterboard) was explored in this study (Figure 13). The topography of the walls differs according to the finish, with some being rougher than others, which may have an effect on the success of the development process used (Kent, 2013a). The results for each development process showed that there were only minor differences when comparing wall finishes with all of the development processes tested (Figure 13). When comparing the overall grades of the fingermarks recovered (using the system described in section 2.3.2.6. and Table 14), it is clear that the quality of fingermarks is wide spread. Each process developed fingermarks at grades 1, 2 and 3, however the only combination to develop excellent quality fingermarks at grade 4 was magneta flake powder on painted plaster; the reason for which is unknown.

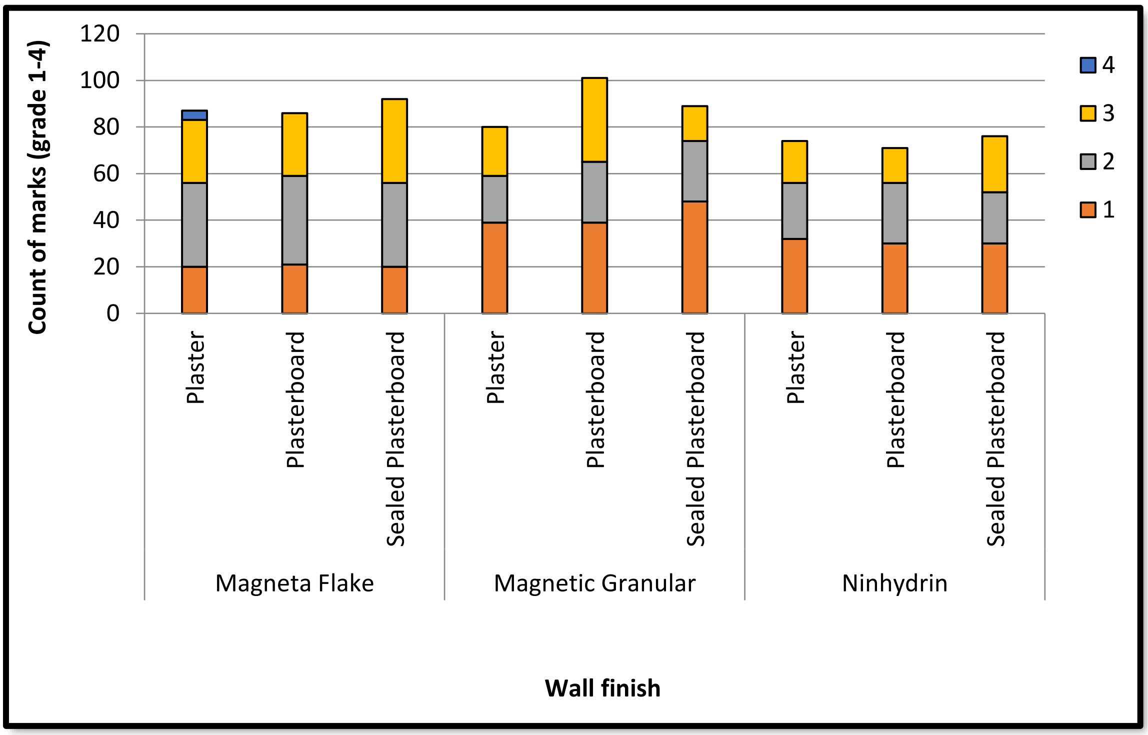


Figure 13 - Chart comparing effect of wall finish (plaster, plasterboard and sealed plasterboard) on graded fingermarks developed with different processes (black magnetic granular powder, magneta flake powder and ninhydrin) using data collated from all paint types combined

The results (Figure 13) showed that for both magneta flake powder and ninhydrin there was a difference of 0.02% between sealed plasterboard (best) and plasterboard (worst). For black magnetic granular powder there was a difference of 0.08% between plasterboard (best) and plaster (worst). The Kruskal-Wallis test was applied to ascertain if any of these differences were significant, but returned p values of 0.96, 0.98 and 0.47 respectively, thus confirming that the differences in results were insignificant at a 95% confidence level.

The overall results from this study found a total of 265 fingermarks when using magneta flake powder, compared with 270 fingermarks with black magnetic granular powder. These results are aligned with current theory and guidelines where magneta flake powder is considered to be "*slightly less effective*" than black magnetic granular powder, which is deemed to be the most efficient powder in developing fingermarks on textured surfaces (Bandey, et al*.,* 2013). These results are beneficial as both CSEs and FLOs can apply powders '*in situ*' at scenes, unlike ninhydrin which can only be applied by FLOs, as CSEs are not trained to use this process.

However, with regards to the quality of developed fingermarks, Figure 13 shows that black magnetic granular powder developed a greater number of fingermarks that were graded as '1', whereas magneta flake powder developed more fingermarks that were graded as '2', which contradicts the above theory (*ibid*). The success of ninhydrin is affected by the method of application, the temperature and relative humidity of the surface, which is difficult to control at a crime scene (Ramminger, et al., 2001; Bandey, et al., 2014; International Fingerprint Research Group, 2014). Therefore, the efficiency of this technique could increase/decrease according to the surroundings of the scene and overall weather conditions. It is possible to use additional equipment, such as portable heaters and humidifiers, to reduce these variables to a certain extent; however, the results for ninhydrin will differ between those developed within a crime scene and those developed in a controlled laboratory using a ninhydrin oven (Bandey, et al*.,* 2014).

2.4.2. Effect of paint type

The results (Table 16) indicated that the paint type clearly had an effect on the efficiency of fingermark development processes.

Table 16 - Total number of fingermarks developed according to paint type (matt, silk, bathroom, eggshell) (N=2160)

Paint type (n=540)	**Number of fingermarks developed (grade 1 to 4)**	**Number of quality fingermarks developed (grade 3 or 4)**
Matt	88 (16%)	15 (3%)
Silk	280 (52%)	47 (9%)
Bathroom	267 (49%)	61 (11%)
Eggshell	305 (56%)	85 (18%)

In total, 2,160 fingermarks were deposited; 540 marks on each paint type, which had been applied to plain plasterboard. The results for the number of fingermarks developed in this experiment show a higher success rate on eggshell paint (56%), whereas very few marks were developed on matt paint (16%). Silk (52%) and bathroom (49%) paint performed similarly. This result was also reflected in the number of quality marks developed (i.e. grades 3 and 4), although the difference noted between paint types was on a smaller scale (3-18%). The overall results were analysed using the Kruskal-Wallis test which returned a p value of <0.05, showing that the difference between the paint types was significant, requiring further in-depth analysis (outlined in sections 2.4.2.1 and 2.4.2.2.). Therefore, it is imperative that practitioners take paint type into account when developing fingermark recovery plans.

The low number of fingermarks recovered from matt paint (16%) is concerning, as this is the most popular paint type bought by consumers (Wickes, 2015). The likelihood of CSEs dealing with this paint type is high; however, the probability of developing latent marks on such paint is low, thus requiring further investigation. Silk paint was the second most frequently purchased paint type (*ibid*) and the number of fingermarks recovered was significantly higher (52%), thus providing CSEs with a more realistic opportunity to develop fingermarks '*in situ*' at scenes. However, the number of quality fingermarks developed (grades 3 and 4) was relatively low for all paint types (3-18%), highlighting that painted walls are not an ideal surface from which to recover fingermarks.

Nevertheless, fingermarks should not be regarded as '*stand-alone*' forensic evidence, as they can support other types of forensic evidence, such as DNA (Kent, 2013b; Bandey, et al., 2014). Fingermarks (whether identifiable or not) can draw attention to an area that has been touched, which could provide a DNA profile to aid the investigation (Van Hoofstat, et al., 1999; Schulz and Reichert, 2002; Bhoelai, et al., 2011). Therefore, it is worth noting the overall number of developed marks (grades 1 to 4), in addition to the number of quality marks (grades 3 and 4 only), so that alternative forensic procedures, such as DNA, can be utilised where possible.

2.4.2.1. Effect of paint type on development processes

This experiment focussed on three processes (black magnetic granular powder, magneta flake powder and ninhydrin) that were identified as being the most frequently used by practitioners in section 2.2.2.2 (Figure 10).

Table 17 - Total number of marks developed (grades 1-4) according to paint type (matt, silk, bathroom and eggshell) and development process (magneta flake powder, black magnetic granular powder and ninhydrin)

Paint type	**Development process**			**Total**
	Magneta Flake	**Magnetic Granular**	**Ninhydrin**	
Matt	0	60	28	88
Silk	32	142	106	280
Bathroom	63	168	36	267
Eggshell	130	171	4	305
Total	225	541	174	940

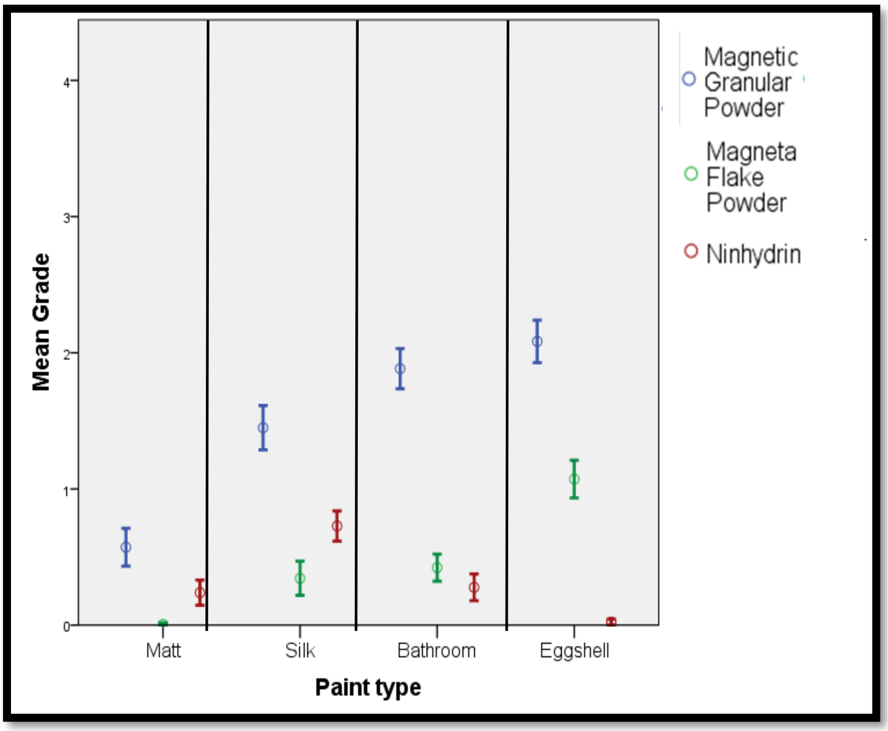


Figure 14 - Chart comparing effect of development process used (black magnetic granular powder, magneta flake powder and ninhydrin) on paint type (matt, silk, bathroom and eggshell) applied to plain plasterboard.

The findings in Table 17 and Figure 14 showed that black magnetic granular powder developed 541 fingermarks (grades 1 to 4), accounting for 58% of all developed fingermarks in this experiment. Black magnetic granular powder out-performed both magneta flake powder, which developed 225 fingermarks (24%) and ninhydrin, which developed 174 fingermarks (18%) on all four paint types. The Kruskal-Wallis test was carried out on all paint types to ascertain whether or not the differences in development process performance was significant, which returned a *p* value of <0.05, thus highlighting that the results were significantly different. Each paint type was then analysed separately to ascertain whether black magnetic granular powder was significantly better than the second-best performing process (i.e. on eggshell paint – black magnetic granular powder vs. magneta flake powder; on silk paint – black magnetic granular powder vs. ninhydrin). The Mann Whitney U test was performed to ascertain whether or not these differences were significant. The test gave a *p* value of <0.05 for all paint types showing that the differences in results were significant.

The relationship between the porosity of paint and effectiveness of development processes is well documented, having an effect on the quantity and quality of fingermarks recovered (Bleay, et al., 2013; Ramotowski, 2013e; Bandey, et al., 2014). Magneta flake powder and black magnetic granular powder are non-porous techniques (which may also be useful on semi-porous surfaces) and therefore they were expected to be more efficient on paint types with a lower pigment volume concentration (PVC), such as eggshell (Hansen, et al., 1994; Paint Quality Institute, 2004). Conversely, ninhydrin is reported to be best suited to porous substrates, (and can also be used on semi-porous substrates) (Bandey, et al., 2014) and therefore it was expected to be more successful on paints with a higher PVC, such as matt (Hansen, et al., 1994; Paint Quality Institute, 2004). However, the results contradict initial expectations regarding the relationship between PVC, porosity and development processes, as shown in Figure 14. Nonetheless, these results are beneficial as both CSEs and FLOs are able to utilise powders '*in situ'*, and therefore they could be used at both volume and serious crime scenes.

These results also contradict those reported in section 2.4.1.2, finding magneta flake powder to be only “slightly less effective” than black magnetic granular powder, which is in line with other research findings (Bandey, et al., 2014). This may be due to the effect of wall finish, which was being tested in the previous experiment, but is likely due to the introduction of donors in this study (previous study used fingermarks controlled through the use of reference pads). This confirms a difference in ‘*real*’ latent marks compared to artificially loaded fingermarks, as discussed in the literature (Sears, et al*.,* 2012; International Fingerprint Research Group, 2014). The preferential development of donors’ marks is discussed in more detail in section 2.4.5. Regardless, these findings are problematic for CSEs, who predominantly use magneta flake powder on painted walls (as discussed in section 2.2.2.2. and Figure 10), which is much less effective than black magnetic granular powder on all paint types. This highlights a training issue, as current guidelines do not recommend the use of magenta flake on any paint types and thus should not be used. Therefore, CSE training should be updated to ensure that they are using powders on appropriate surfaces, and in accordance with ISO 17020 requirements.

The findings for matt paint highlight that ninhydrin is not an effective method to use. This opposes current guidelines regarding the development processes that should be applied, which recommend ninhydrin (with consideration being given to powder suspension) (Bandey, et al*.,* 2014). At present, there is no recommendation for black magnetic granular powder on matt paint (*ibid*). The low number of marks developed using ninhydrin could be due to the environmental conditions surrounding the simulated walls during the post-development period. This issue is usually addressed by using a ninhydrin oven to control environmental conditions, which was not used in this study in order to mimic scene conditions. If the substrate is too cold/dry then the amino acids would not fully react with the ninhydrin solution, producing partially developed marks (Ramminger, et al., 2001).

However, this would not explain the number of marks developed on silk paint, which also confirms the findings from Lawrence, et al., (2010), who reported a similar success rate with ninhydrin being used on silk paint. A suggestion for such differences may be due to the disparity in porosity of modern silk paints, compared with older compositions of silk paints. However, this cannot be confirmed due to the unavailability of such information from paint manufacturers.

The significantly higher number of marks developed using black magnetic granular powder on matt paint is also inconsistent with expectations for high PVC paints with increased porosity. This may indicate that the latent fingermarks are not being fully absorbed into the paint, as noted with other porous substrates, leaving some residue on the surface (Kent, 2013a; Bandey, et al., 2014). The remaining results for silk, bathroom and eggshell paint were in line with the original hypothesis, showing that black magnetic granular powder was effective at developing latent fingermarks on these more non-porous paints. Nevertheless, the difference in success rates between black magnetic granular powder and magneta flake powder is significant (as shown in the results from the Kruskal-Wallis and Mann Whitney U tests) and challenges the general notion that magneta flake is only slightly less effective than black magnetic granular powder on textured substrates (Bandey, et al., 2014). The findings from this experiment show that of the three development processes tested, black magnetic granular powder is the most efficient and consistent process to develop latent fingermarks on painted walls (Figure 14).

When powders were used to develop fingermarks, heavy background staining was noted on some paint types (i.e. eggshell) compared to others (i.e. matt) (Figure 15). This was more prominent when using black magnetic granular powder than magneta flake powder, which may be due to the microstructure of the powder particles, as shown in Figure 8. The powders adhered to the eggshell paint immediately upon application and therefore the surfaces needed to be powdered lightly (with only minimal powder coming into contact with the surface) to prevent marks becoming over-developed.

Due to the preferential adhesion to the background, any fingermarks developed by the powders remained a lighter colour (Figure 16) and therefore did not have the same level of contrast as fingermarks where the powder had adhered to the ridges. Background staining was also noted when ninhydrin was applied to bathroom paints, however this was minimal and did not interfere with the contrast of the fingermarks developed.

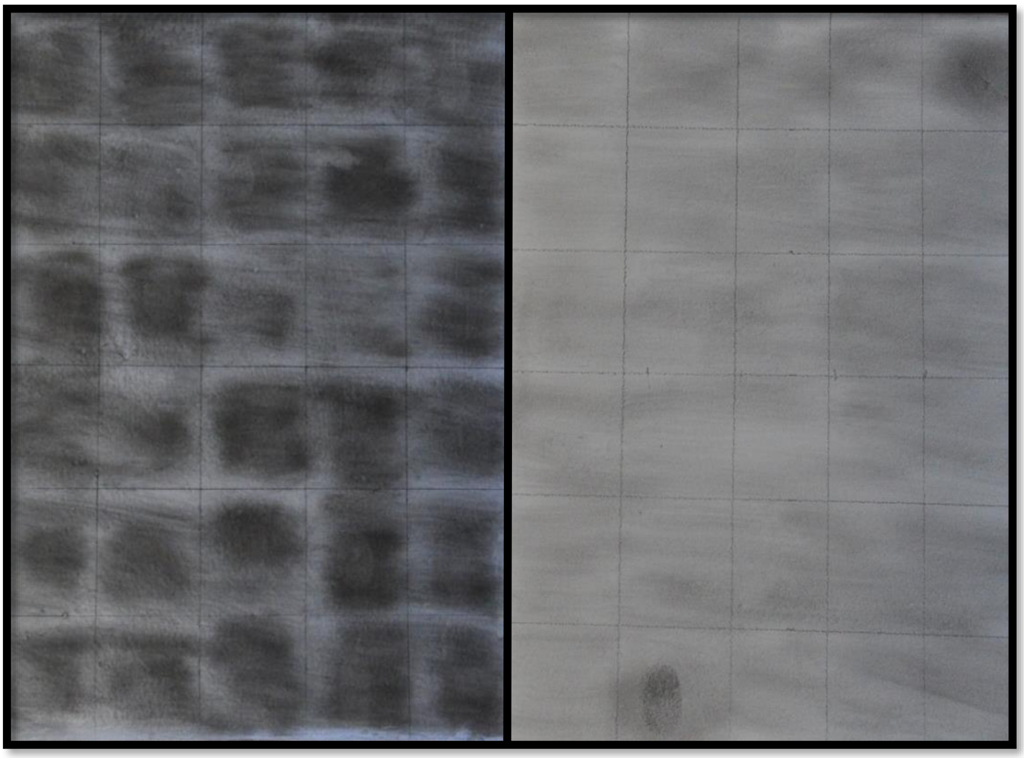


Figure 15 - Heavy background staining on eggshell paint (left) compared to matt paint (right) when using black magnetic granular powder

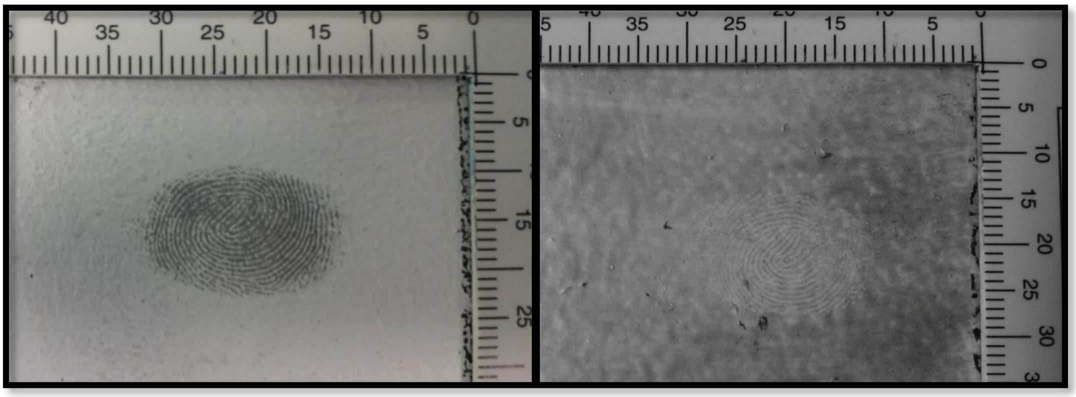


Figure 16 – Black magnetic granular powder adhering to the ridges on bathroom paint (left) compared to background adherence on eggshell paint (right)

2.4.2.2. Effect of paint type on the ageing of fingermarks

This study examined simulated walls on three separate occasions (i.e. a day, a week, and a month after deposition of fingermarks) and therefore the quality and quantity of fingermarks were expected to decrease over time, regardless of the process used or paint type (Figure 17).

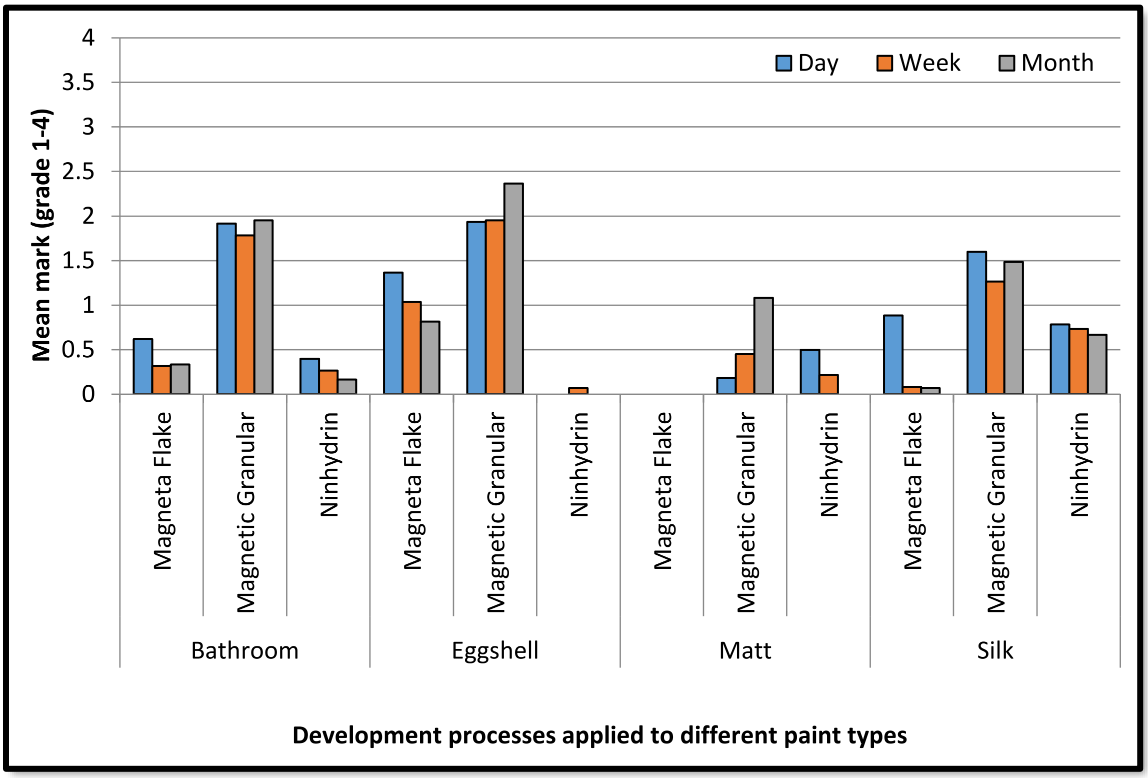


Figure 17 - Chart comparing effectiveness of paint type (bathroom, eggshell, matt and silk) and development process (magneta flake powder, black magnetic granular powder and ninhydrin) over time.

It is widely accepted that fingermarks degrade with age, with the majority of development processes (including powders and ninhydrin) decreasing in effectiveness as time progresses (Yamashita and French, 2011; Ramotowski, 2013e; Bandey, et al., 2014). The findings for ninhydrin were as expected, showing a uniform decrease in marks for all paint types, apart from eggshell paint which had an unusual ‘one-off’ result. The Kruskal-Wallis test was used to determine the significance of the ninhydrin results. The test returned a *p* value of <0.05 for the differences in results of ninhydrin on matt paint, proving this to be significant; whereas the other tests for ninhydrin showed insignificant differences (*p* values between 0.24 and 0.79).

The findings for both powders did not follow the expected declining pattern. Magneta flake powder showed a decrease in marks when applied to eggshell and silk paint over time, and produced no results on matt paint, which is problematic as this is the powder most commonly used by CSEs, as discussed in section 2.2.2.2. The results for bathroom paint showed a decrease in marks between a day and a week, but then a small increase after a month. The Kruskal-Wallis test was applied to the findings for magneta flake where a *p* value of <0.05 for eggshell and silk paint was obtained, showing that the difference in results over time was significant. Conversely, the test showed that the differences for magneta flake powder on bathroom paint over time was not statistically significant (*p* value of 0.29).

In contrast, black magnetic granular powder showed mixed results on all paint types. When applied to bathroom and silk paint there was also a decrease in marks between a day and a week, but then a small increase after a month. Nonetheless when applied to eggshell and matt paint there was an increase in results over time, which was particularly noticeable on matt paint. The Kruskal-Wallis test was applied to the results for black magnetic granular powder on the different paint types over time and a *p* value of <0.05 was returned for its use on matt paint, thus proving that the difference in those particular results were significantly different. The *p* values for its use on other paint types over time were much higher (between 0.11 and 0.51) showing that the differences were not statistically significant at 95% confidence level.

The findings for black magnetic granular powder on matt paint contradicts the usual ideology that powders are less efficient at developing aged marks (Yamashita and French, 2011; Bandey, et al., 2014). An increase in results over time has been previously noted when black magnetic granular powders have been used on wooden furniture (Bandey and Hardy, 2006; Bleay, et al., 2013), thus highlighting that, whilst this is unusual, it is not an anomaly

2.4.3. Effect of paint brand

The results (Table 18) indicated that the brands of paint used did have an effect, some of which show significant differences at 95% confidence level (as discussed later in this section). All of the paints used were aqueous based paints, apart from Wickes Trade eggshell which was solvent based.

Table 18 - Total number of fingermarks developed according to paint brand (N=1728)

Paint Type	Paint Brand (n=144)	VOC Level g/L	Number of fingermarks developed (grade 1 to 4)	Number of quality fingermarks developed (grade 3 or 4)
Matt	Homebase Value Vinyl Matt (Brilliant White)	15	18 (13%)	0
	Wickes Trade Flat Matt (White)	1	13 (9%)	1 (0.001%)
	B&Q 'Colours' Matt (Magnolia)	1	35 (24%)	3 (2%)
	Dulux Matt (Pebble Shore)	3	10 (7%)	0
	Dulux Matt (Polished Pebble)	3	10 (7%)	0
	Homebase Kitchen and Bathroom Matt (Brilliant White)	20	49 (34%)	5 (3%)
Non-Matt	Homebase 'Home of Colour' Kitchen and Bathroom (Soothing White)	15	33 (23%)	2 (1%)
	Homebase Silk (Brilliant White)	10	99 (69%)	56 (39%)
	Wickes Trade Vinyl Silk (White)	1	55 (38%)	7 (5%)
	Dulux Silk (Almost Oyster)	1	53 (37%)	9 (6%)
	Wickes Trade Eggshell (White)	30	69 (48%)	6 (4%)
	Homebase 'Home of Colour' Duracoat (Soothing White)	15	45 (31%)	3 (2%)

In total, 1,728 fingermarks were deposited on simulated walls; 144 marks on each paint brand. The results for the six matt paints and six non-matt paints (Table 18) were compared using statistical tests. The Kruskal-Wallis test was performed for the set of six matt paints and also for the set of six non-matt paints, both producing p values of <0.05, showing there to be significant differences in the results. Therefore, the brand of paint does have an effect on the development of latent fingermarks on painted walls at scenes.

When analysing the six matt paints tested in this experiment, two paints (B&Q 'Colours' matt and Homebase kitchen/bathroom matt) developed a larger quantity of fingermarks (grade 1 to 4) compared to the other matt paints. The results of the Homebase kitchen/bathroom matt paint was expected to vary from the other traditional matt paints, due to the properties highlighted on the packaging of this particular paint, making it "tough, washable, moisture and grease resisting". However, there is nothing on the packaging of the B&Q 'Colours' matt paint to suggest that there are any additives in this paint that are not present in general matt paint.

One proposal for the differences in overall results is the composition of the paints (relating to Volatile Organic Compound (VOC) levels), due to the introduction of the EU Directive 2004/42/EC (updated in 2010). Whilst the precise date of manufacture or purchase is unknown for most of the matt paints, all paints indicated the latest update of this EU legislation (2010), limiting VOC levels to a maximum of 30 g/L. Nevertheless, the matt paints did vary in VOC levels (1-20 g/L) (Table 18) with Homebase kitchen/bathroom matt paint containing a maximum 20 g/L VOC. However, the B&Q 'Colours' matt paint had a much lower VOC content (1 g/L), which refutes the suggestion that the composition relating to VOC levels may have an implication on the results.

Despite there being differences in the overall number of fingermarks found (grades 1 to 4), the results for quality fingermarks (grades 3 and 4 only) showed little differences. Therefore, in operational circumstances the brand of matt paint should not have an effect on the number of quality fingermarks developed, but will affect the detection of areas that could be tested for DNA, as previously discussed in section 2.4.2. (Kent, 2013b; Bandey, et al., 2014). This information needs to be taken into consideration when validating processes under ISO 17020 and 17025.

The non-matt paints showed better results (grades 1 to 4), with Homebase silk paint providing more fingermarks (69%) than the other five paints (23%, 38%, 37%, 48% and 31% respectively). Therefore, to analyse the results further the Mann Whitney U test was performed to compare the best performing non-matt paint against the next best performing paint (Wickes Trade eggshell) to ascertain if the results were statistically significantly higher. The Mann Whitney U test returned a p value of <0.05 when comparing Homebase silk (best performing non-matt paint) against Wickes Trade eggshell (2nd best), proving the result to be significantly higher. A suggestion for this would be the age of the paint (as discussed above), however all packaging states the latest EU legislation, meaning that the paint was manufactured after 2010. Also, the VOC content for this particular paint (10 g/L) was in line with the average VOC levels for the other non-matt paints tested in this experiment. Therefore, additional microscopy and spectroscopy work is required to highlight additional reasons for these findings (Chapter 3).

2.4.3.1. Effect of paint brand on development processes

This experiment focussed on three processes (black magnetic granular powder, magneta flake powder and ninhydrin) that were identified as being the most frequently used by practitioners in section 2.2.2.2 (Figure 10). These were used on six different matt paints and six non-matt paints to ascertain whether or not different brands of the same paint type affected the efficacy of the development processes (Table 19 and Figure 18).

Table 19 - Total number of marks developed (grades 1-4) according to paint brands and development process (magneta flake powder, black magnetic granular powder and ninhydrin)

Paint Type	Paint Brand	Development process			Total
		Magneta Flake	Magnetic Granular	Ninhydrin	
Matt	Homebase Value Vinyl Matt (Brilliant White)	3	9	6	18
	Wickes Trade Flat Matt (White)	0	9	4	13
	B&Q 'Colours' Matt (Magnolia)	0	21	14	35
	Dulux Matt (Pebble Shore)	0	8	2	10
	Dulux Matt (Polished Pebble)	1	5	4	10
	Homebase Kitchen and Bathroom Matt (Brilliant White)	6	19	24	49
Non-Matt	Homebase 'Home of Colour' Kitchen and Bathroom (Soothing White)	2	16	15	33
	Homebase Silk (Brilliant White)	38	42	19	99
	Wickes Trade Vinyl Silk (White)	5	30	20	55
	Dulux Silk (Almost Oyster)	19	19	15	53
	Wickes Trade Eggshell (White)	46	19	4	69
	Homebase 'Home of Colour' Duracoat (Soothing White)	6	24	15	45
Total		126	221	142	489

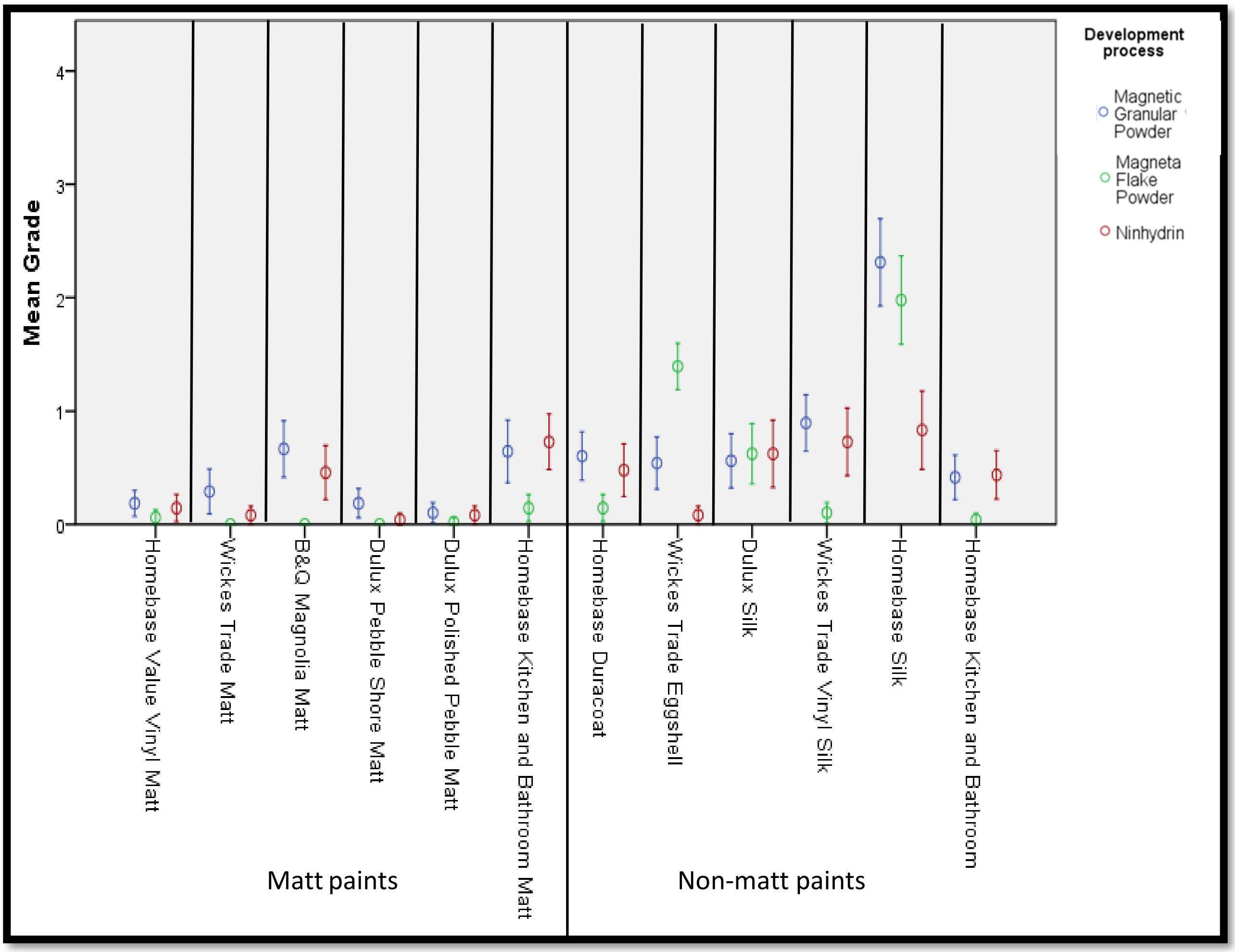


Figure 18 - Chart comparing effect of both matt and non-matt paint brands on development processes (black magnetic granular powder, magneta flake powder and ninhydrin)

It is important to explore the relationship between porosity of the paint and the efficacy of development processes, as discussed in section 2.4.2.1, (Bleay, et al., 2013; Ramotowski, 2013e; Bandey, et al., 2014). Of all the fingermarks that were developed in this experiment (n=489), 45% were developed using black magnetic granular powder, 26% were developed using magneta flake powder and 29% were developed using ninhydrin. These results differ from those noted in previous experiments (discussed in section 2.4.2.1 - magnetic granular, 58%; magneta flake, 24%; ninhydrin, 18%), where a more significant difference was noted between black magnetic granular powder and the other two development processes.

Nevertheless, the Kruskal-Wallis test was applied to the results of this experiment, which returned a *p* value of <0.05, showing that both sets of data produced significantly different results at 95% confidence level. On the other hand, it is recognised that the previous experiments were carried out using donors' fingermarks, whereas these experiments used amino acid/sebaceous reference pads and therefore the two are not directly comparable.

The effect of development processes used on different non-matt paint brands (n=6) varied. The Kruskal-Wallis test was used to ascertain the significance of the results shown in Figure 18. The *p* values returned were <0.05 for all paint brands, apart from Dulux silk, showing significant differences between the development processes used on each paint type. The *p* value provided for Dulux silk, was 0.89 thus proving that the result for this paint brand was not statistically different. Black magnetic granular powder performed best on over 50% of the paint brands tested and developed a large number of fingermarks on Homebase silk paint. This result corresponds with the Home Office guidelines regarding the development of fingermarks on non-matt painted walls (i.e. silk, satin, eggshell, bathroom), which recommends using black magnetic granular powder as part of a sequence (Bandey, et al*.,* 2014). However, CSEs currently favour magneta flake powder rather than utilising black magnetic flake powder (as discussed in section 2.2.2.2), which is not recommended for use on painted walls. This highlights the need for continual professional training for CSEs in particular to ensure that they are aware of current guidelines and are using the correct powders according to the substrate that they are examining.

On the other hand, the results from Dulux silk, Wickes Trade eggshell, and Homebase kitchen/bathroom paint developed more fingermarks with either ninhydrin or magneta flake powder. Inter-paint type differences (i.e. Duracoat vs. silk) were expected to be more distinct, but not intra-paint type differences (i.e. silk vs. silk). These results may be due to the topography of the paint (particularly those from Wickes Trade eggshell) and therefore additional microscopy and spectroscopy work is required to highlight reasons for these findings (Chapter 3).

The effect of development processes used on different matt paint brands (n=6) was also analysed using the Kruskal-Wallis test. The p values returned were <0.05 for all paint brands, apart from Dulux Polished Pebble matt and Homebase Value Vinyl matt, showing significant differences in results. The p value provided for Dulux Polished Pebble matt (0.25) and Homebase Value Vinyl matt (0.16) showed that the results for these paint brands were not statistically different. Black magnetic granular powder was the most effective process used on the matt paints, with 83% of the brands showing better results with this, compared to magneta flake or ninhydrin. These findings disagree with current Home Office guidelines regarding matt paint, which do not recommend using black magnetic granular powder (Bandey, et al., 2014).

Nevertheless, when analysed further (Figure 19) it is clear that whilst black magnetic granular powder performed best (54%), ninhydrin (which is recommended by the Home Office), also performed well (40%). Conversely, magneta flake powder performed poorly on the matt paints (6%). This is particularly problematic, as CSEs are more likely to encounter matt painted walls at crime scenes (as shown in Figure 2) and magneta flake was the most popular development method being used on walls (as shown in Figure 10). Therefore, it is likely that a large number of latent marks have not been developed on painted walls at scenes, due to incorrect processes being used '*in situ*'. These findings emphasise the need for additional CSE training to ensure that black magnetic granular powder is the only powder being used on painted walls. However, it is anticipated that this issue will be resolved due to the introduction of mandatory ISO accreditation of both FLOs and CSEs.

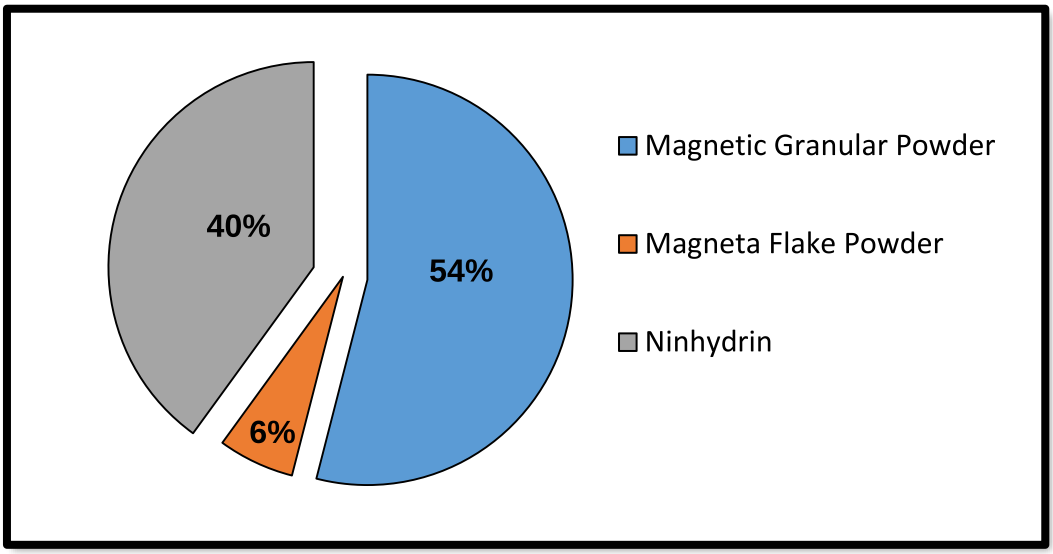


Figure 19 - Chart comparing performance of development processes (black magnetic granular, magneta flake and ninhydrin) used on matt paints

However, these findings differ from the results discussed in section 2.4.2.1, where ninhydrin was found to be much less effective. Overall the quality of fingermarks developed on different paint brands were poor, as shown in Figure 18, apart from Homebase silk. The lack of quality marks developed may be due to the topography of the substrate, as discussed in section 2.4.3.3.

2.4.3.2. Effect of paint brand on the ageing of fingermarks

As discussed in section 2.4.2.2, the effectiveness of the development processes used in these preliminary studies are expected to decrease as time progresses (Yamashita and French, 2011; Ramotowski, 2013e; Bandey, et al*.*, 2014). The results for this experiment (Figure 20) were consistent with these expectations and showed a decrease in results for all paint types, apart from Homebase silk, Homebase kitchen/bathroom, Wickes Trade eggshell, Wickes Trade matt and Dulux Pebble Shore matt.

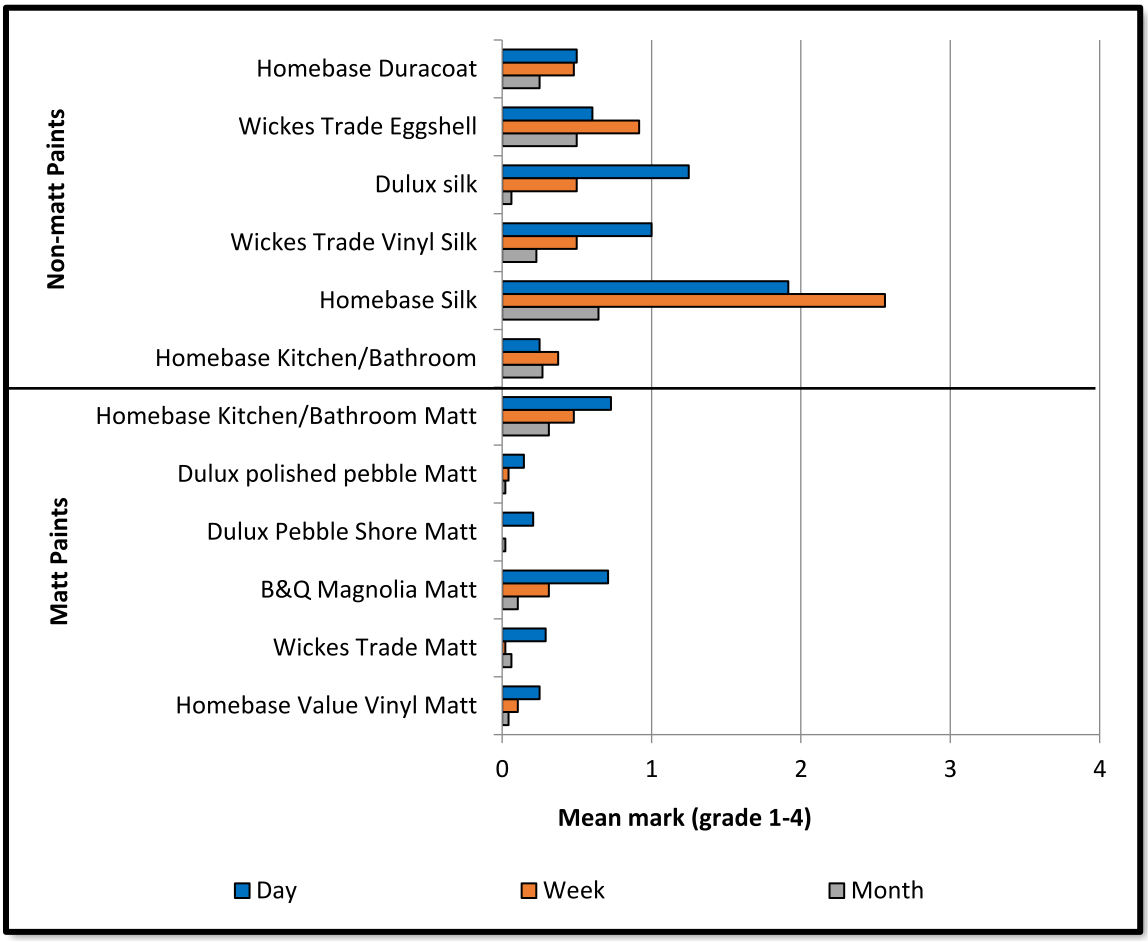


Figure 20 - Chart comparing the effectiveness of paint brands (both matt and non-matt) over time (using combined data from black magnetic granular powder, magneta flake powder and ninhydrin)

Three of the named paints (Homebase silk, Homebase kitchen/bathroom, Wickes Trade eggshell) showed an increase in developed fingermarks a week after deposition, which then decreased again after a month. On the other hand, two of the named paints (Wickes Trade matt and Dulux Pebble Shore matt) showed a decrease in marks after a week, but an increase after a month. These irregularities are linked to black magnetic granular powder, as previously highlighted in section 2.4.2.2, which has also been noted in literature (Bandey and Hardy, 2006; Bleay, et al*.*, 2013).

2.4.3.3. Effect of paint application on development of fingermarks

One factor that may have had an increased impact on the results of this experiment is the topography of the painted simulated walls. Due to the size of the strips to be painted on each board, a brush was used to apply the paint instead of a roller, and therefore striations were present on the surface (Figure 21). As the texture of the surface is known to have an impact on the deposition of fingermarks, and some development processes, this may have affected the results in this study (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014). Such issues may be encountered at scenes, but will be primarily located on window frames, windowsills and radiators, rather than walls where rollers are generally used to apply paint.

Figure 21 - Image showing striations in brushed paint with developed ninhydrin fingermarks

2.4.4. Increase/decrease of ninhydrin marks over time

The effectiveness of ninhydrin when used at scenes can vary depending upon the temperature and relative humidity in the area concerned; some of which can be mitigated through the use of heaters and humidifiers (Kent, 2013b; Bandey, et al., 2014). Nevertheless, this process may take several days (or even weeks) to fully react (*ibid*). With the focus of this study being on the development of fingermarks '*in situ*' on painted walls, scene conditions were adhered to and therefore a ninhydrin oven was not used and the simulated walls were maintained at room temperature (18ºC and 45% RH).

Once treated with ninhydrin, the simulated walls were assessed on three separate occasions (3 days, 10 days and 17 days post-treatment) and the visible fingermarks graded each time. This was due to the uncertainty of the optimum time that ninhydrin should be left to react with the amino acids present in the latent fingermarks, before the marks started to fade. It is important to note that no time frame is outlined in the Home Office guidelines (Bandey, et al*.,* 2014), leaving individuals to decide on an appropriate time frame. These preliminary studies showed that fingermarks that had developed with ninhydrin were most prominent 3 days post-treatment, and most had begun to fade (or had faded completely) by 10 days post-treatment. Therefore, if ninhydrin is used at crime scenes by FLOs, it is vital that the treated area is monitored regularly to record any fingermarks that develop. Further research is needed to ascertain a more precise time frame in which to develop fingermarks with ninhydrin under general room conditions '*in situ*' (discussed in section 4.3.1.).

2.4.5. Preferential development of donors' fingermarks

It is widely accepted that the inter- and intra-variability of donors' marks vary considerably (Frick, et al., 2013; Stubbs, et al*.,* 2015; Fritz, et al., 2017). Therefore, the data collected during experiments involving donors (N=30) (outlined in section 2.4.2) was analysed further to ascertain whether or not their deposited marks showed a preference for powders, (a non-porous process, targeting various components of fingermark residue) or ninhydrin (a porous process, targeting amino acids). The results (Figure 22) show a mix of preferences. 37% of donors developed more marks with ninhydrin, compared to powders, indicating higher levels of amino acids, whereas 57% of donors developed more marks with powders. 6% of donors provided fingermarks that developed equally well with both processes. This information should be taken into account when designing fingermark development plans, as if only one development process is utilised, such as ninhydrin, then a large percentage of marks would be left latent. Therefore, it is vital that sequential processing is used in order to maximise the yield of fingermarks from crime scenes (Bandey, et al., 2014).

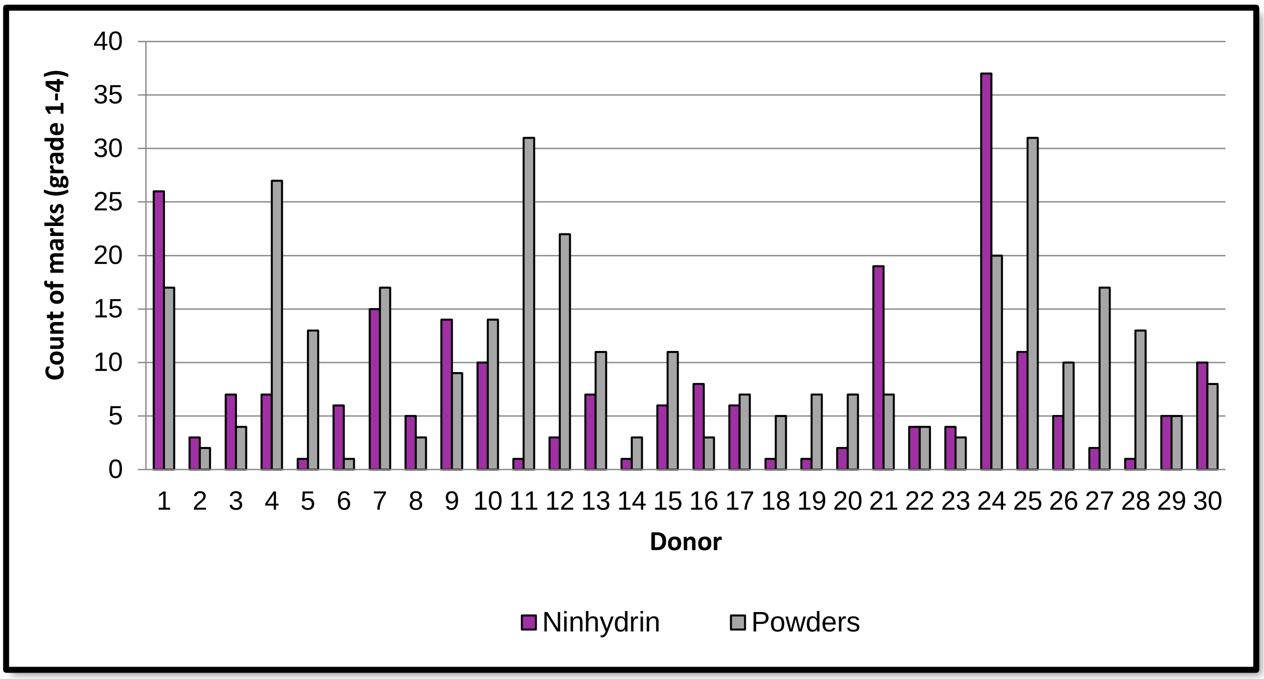


Figure 22 - Chart comparing donors' preferential development with either ninhydrin or powders

2.5. Conclusion

These preliminary studies have shown that painted walls cannot be viewed as a single substrate type and therefore consideration must be given to the specific type of paint on the walls prior to any fingermark development process being applied. This was identified by 64% of the practitioners who were surveyed at the beginning of the study (in section 2.2.2.2.), highlighting the need to visually assess the topography of the painted walls.

In contrast, 13% of practitioners indicated that they did not consider the type of paint applied to the walls, thus treating all painted walls the same. Therefore, the aim of the preliminary experiments was to establish whether or not the type/brand of paint applied to the wall had an effect on the development of fingermarks.

The three most commonly used development processes determined from the survey were used throughout the preliminary experiments to ascertain their effectiveness on a variety of paints. The development processes were first tested on different wall finishes (plaster, plasterboard, and sealed plasterboard) to determine whether or not these made a difference to the development of fingermarks. This experiment showed that wall finish does not have a significant impact on fingermarks, and does not need to be taken into consideration by practitioners at crime scenes.

On the contrary, the type and brand of paint does have a statistically significant effect on the development of fingermarks. The type of paint (matt, silk, bathroom and eggshell) showed distinctly different results, with the most frequently bought paint (matt) proving to be a difficult surface on which to develop latent fingermarks. More fingermarks were recovered on other paint types, particularly eggshell, however the probability of encountering these paint types on the walls of crime scenes is not as high. The brand of the paints also showed a wide range of results, with some brands providing better results than others; many of which were significantly higher. The results also showed that black magnetic granular powder was the most effective process on all paint types, which is concerning, as the results of the questionnaire showed that CSEs prefer to use magenta flake powder. This highlights the need for the continual professional development of CSEs to ensure that they are utilising the correct powder type on each substrate.

In order to understand these differences in more detail, microscopy and spectroscopy examinations have been completed (Chapter 3). The findings from these preliminary studies, in addition to the microscopy/spectroscopy work, have informed the final experiments to ascertain which development processes are the most effective at developing latent fingermarks on painted walls '*in situ*' at crime scenes (Chapter 4).

Chapter 3 – The physical relationship between paint and fingermarks

3.1. Introduction

The aim of this chapter is to explore the microscopic properties of paints that affect the development and recovery of fingermarks from walls at crime scenes. As discussed in Chapter 2, the type and brand of paint has a significant effect on the efficacy of fingermark development processes used on painted walls. Nevertheless, it is not clear whether the relationship between fingermarks and the surface structure of the paint is the primary factor in these findings. It is widely accepted that the topography and morphology of substrates has an effect on the deposition and development of latent fingermarks (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014), and therefore it is important to assess whether or not the structure of painted walls and surface texture is the primary factor for the preliminary results.

There is a wide array of literature detailing many aspects of forensic paint analysis (SWGMAT, 2011; Stuart, 2013; Zhang, et al., 2016), however these primarily concentrate on the analysis of paint compositions and the comparison of samples, rather than the surface level detail of the applied paint. Thus, this information cannot aid in explaining the results obtained in Chapter 2. Other subject areas, primarily material sciences, have published literature regarding the morphology and topography of coatings (Tiarks, et al., 2002; Kugge, 2004; Najjar, et al., 2006). Therefore, all of this information will be used and applied in this chapter, along with other literature that discusses the relationship between surface texture (of other substrates, such as plastics) and fingermarks (Jones, et al., 2010; Yamashita and French, 2011; Bandey, et al., 2014).

The aim of this chapter was to investigate the morphology and topography of dried paint to ascertain if it has an effect on the development of latent fingermarks, and if so, to what extent. These characteristics were explored in four separate experiments (optical microscopy, SEM, SEM-EDX and the ‘wipe tests’) studying various aspects of paint and how these interact with deposited fingermarks on simulated walls. Gloss paint was also examined as part of the microscopy experiments (alongside matt, silk, bathroom and eggshell), as it is well known to be a non-porous substrate, due to its low PVC (Paint Quality Institute, 2004). Therefore, other paints could be compared to this on a micro-scale to ascertain whether or not they were also non-porous.

3.2. Materials and methods

The results gained in Chapter 2 were used to inform and design the methodology of the experimental work in this chapter.

3.2.1. Materials

Homebase gloss (white) was purchased from Homebase, UK; Impega white A4 (210 x 297 mm) paper (093-057-621) was purchased from Impega (now Lyreco), France; OTL yellow kitchen and bathroom microfibre cloth, OTL pink multipurpose microfibre cloth, OTL blue glass and mirrors microfibre cloth, Microban purple heavy duty scouring pads, Superbright yellow and green sponge scourers were all purchased from Savers, UK; ethanol (CAS-64-17-5 - HPLC Grade), ethylene glycol (CAS-107-21-1 - extra pure), glass beakers (various sizes) and disposable pipettes (3.2 ml) were all purchased from Fisher Scientific, UK; Triton X-100 (CAS-9002-93-1) was purchased from Sigma Aldrich, Germany; 12mm spectro tabs (G3358) and 0.5’’ SEM pin stubs 6mm length (G301F) were both purchased from Agar Scientific, UK. All other materials were purchased as described in Chapter 2 - section 2.3.1.

3.2.2. Methods

3.2.2.1. Preparation of paint samples

14 sheets of Impega white A4 paper (one per paint) were utilised. Only one paint type (Table 20) was applied to each sheet of paper using a medium pile mini roller to provide an even layer of paint. Three layers of paint were applied to each surface, which were allowed to dry for 24 hours between coats. The paints used in this chapter are the same as those used in Chapter 2, with the addition of gloss paint, which was included as a known non-porous surface for comparison purposes. These samples were used for optical microscopy, SEM and SEM-EDX analysis.

Table 20 - Paint types used in Chapter 3 studies.

Paint Type	Paint Brand
Matt	Wickes Trade Flat Matt (White)
	Homebase Value Vinyl Matt (Brilliant White)
	B&Q ‘Colours’ Matt (Magnolia)
	Dulux Matt (Pebble Shore)
	Dulux Matt (Polished Pebble)
	Homebase Kitchen and Bathroom Matt (Brilliant White)
Non-Matt	Wickes Trade Vinyl Silk (White)
	Wickes ‘Colour at Home’ Bathroom (White)
	Wickes Trade Eggshell (White)
	Homebase Silk (Brilliant White)
	Dulux Silk (Almost Oyster)
	Homebase ‘Home of Colour’ Duracoat (Soothing White)
	Homebase ‘Home of Colour’ Kitchen and Bathroom (Soothing White)
	Homebase Gloss

3.2.2.2. Optical microscopy samples preparation

The materials used during optical microscopic analysis were: Wickes Trade Flat Matt, Wickes Trade Vinyl Silk, Wickes 'Colour at Home' Bathroom, Wickes Trade Eggshell, and Homebase Gloss painted papers (detailed in sections 2.3.1, and 3.2.1). Samples were analysed using Scientific Working Group on Material Analysis guidelines (SWGMAT, 1999; SWGMAT, 2002). Sections were cut (50 x 30 mm) from the painted sample and placed directly onto the stage without any further preparation taking place. An Olympus SZ61 microscope was used to analyse the samples at 10x magnification, and images were captured using an Olympus DP20 camera attachment.

3.2.2.3. SEM/EDX sample preparation

Samples from each of the painted papers (discussed in section 3.2.2.1) were cut into small sections (10 x 10 mm) using a scalpel, and were adhered to SEM pin stubs, using spectro tabs. Each sample was mounted flat on the pin stubs in order to allow for the analysis of surface features (SWGMAT, 2002). The samples were then gold coated (thickness of 5 nm) using a Quorum – Q150RS to increase conductivity before being placed in the specimen holder of the SEM. The samples were analysed using a Zeiss – EVO HD15 SEM, with integrated EDX. All variables, apart from magnification, were kept constant throughout the analysis (Electron High Tension (EHT) – 15.00 kV; Working Distance (WD) – 8.00 mm; Probe – 250 pA) in order that samples could be fully compared. Images were taken from the SEM at 500x, 5000x, and 25,000x magnifications.

3.2.2.4. Preparation of paint samples for wipe test

Sheets of Knauf Plasterboard (200 x 300 mm) (N=36) were painted with one paint type, as stated in Table 13 (except gloss, which was not used for the wipe test experiments). Each paint type was applied to the substrate using a medium pile mini roller. Each board received 3 coats of the same paint, with a drying period of 24 hours between coats, as discussed in section 2.3.4.

The substrates were stored in general room conditions until required for testing, to mimic the environmental conditions associated with indoor crime scenes, such as fluctuations in natural light occurring through an adjacent window.

3.2.2.5. Preparation of suspension solution for 'wipe tests'

The suspension solution was prepared in accordance to the Home Office Fingermark Visualisation Manual for powder suspensions (Bandey, et al., 2014). 250 ml of Triton-X 100 was combined with 350 ml of ethylene glycol and 400 ml deionised water to produce the suspension solution. This was stored at room temperature until used.

3.2.2.6 Application and grading of 'wipe test'

Each piece of painted plasterboard was divided into smaller sections (30 x 30 mm), which was used to test a variety of wiping methodologies to ascertain if it was possible to differentiate between matt and non-matt paints (Figure 23). Each column on the board was labelled with one application method, such as 'wipe once', 'rub for 5 seconds' (in a circular motion), or 'rub for 10 seconds' (in a circular motion); which were carried out with either a dry or wetted cloth.

For each of the wetted cloths (N=6) (cut into 50 x 50 mm sections), 1 ml of each solution (tap water, ethanol or suspension solution) was pipetted on to it before being immediately applied to the surfaces. One cloth was then used to wipe one of the painted substrates. Each row on the boards was labelled with the type of cloth used, such as purple scouring pad or yellow kitchen and bathroom cloth. Each cloth type was then applied in the appropriate motion within the designated box on the board and the amount of paint that had adhered to the cloth was then graded accordingly using a scale (Table 21). All tests were completed in triplicate.

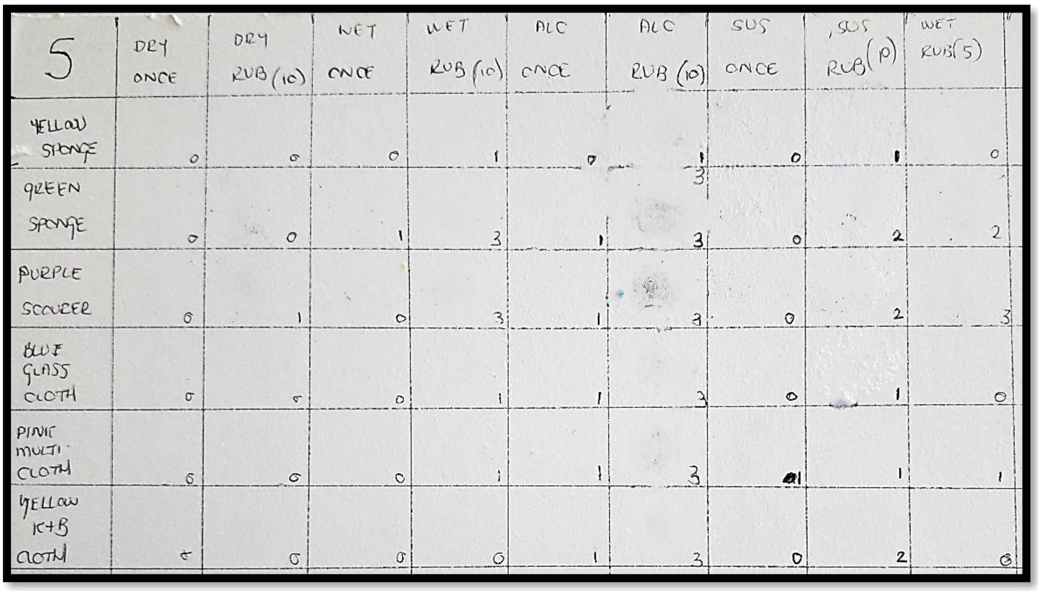
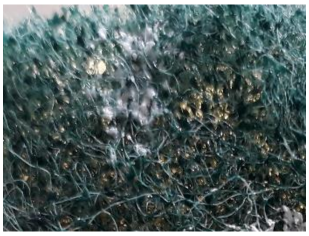
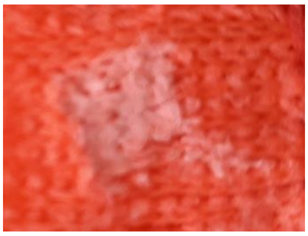


Figure 23 - Image of silk painted board used in ‘wipe tests’, with associated grades noted

<u>Table 21 - Grading system used for ‘wipe tests’</u>

Grade	Description	Image
0	No visible paint transfer onto the cloth	
1	Light paint transfer onto the cloth	
2	Medium paint transfer onto the cloth	
3	Heavy paint transfer onto the cloth	

3.2.3. Statistical analysis

All grades were stored electronically and assessed to determine whether the data was parametric or non-parametric (as described in section 2.3.8). All of the data gained in this chapter was non-parametric and therefore the Mann-Whitney U test (comparing two means) and the Kruskal-Wallis test (comparing more than two means) were utilised to ascertain whether or not the results were statistically significant at a 95% confidence level.

3.3. Results and discussion

3.3.1. Optical microscopy of paint samples

At present there is no validated method to measure the detailed appearance of a painted surface as seen by the human eye (Gunde, et al., 2007). Figure 24 shows images of different paint types, obtained at 10x magnification, which assisted in identifying the main features and differing characteristics of the paints.

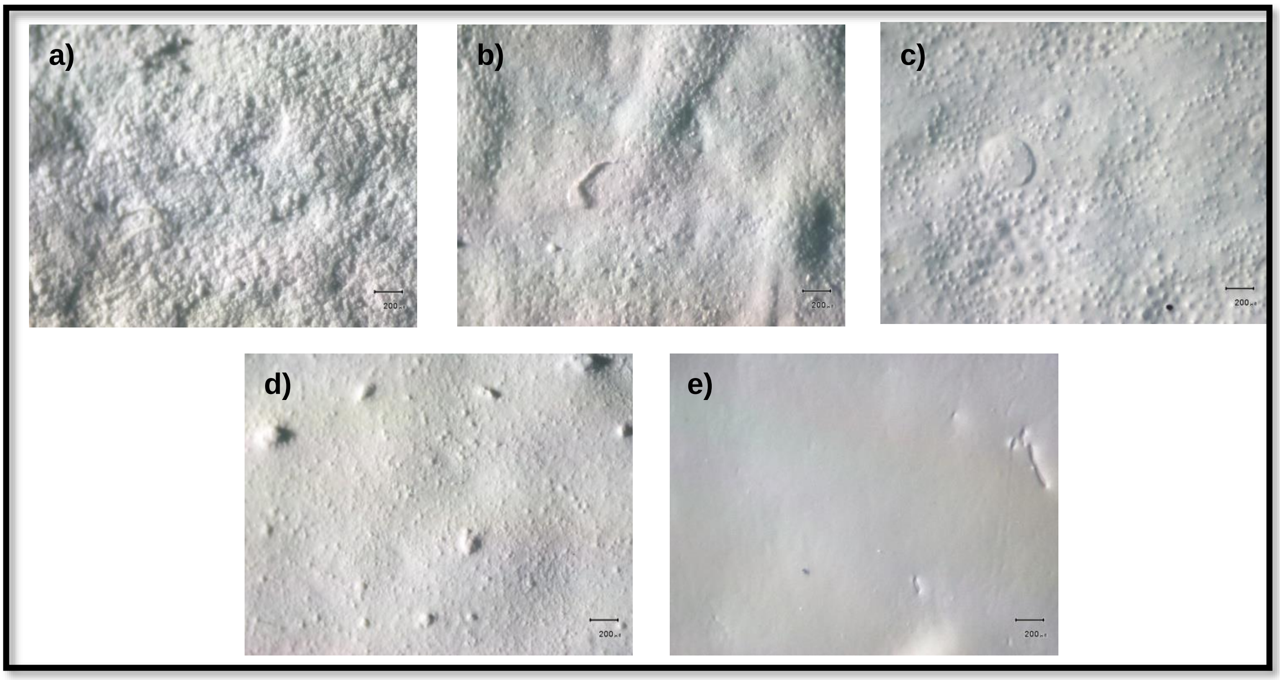


Figure 24 - Optical microscopy images (to scale) of (a) Matt paint, (b) Bathroom paint, (c) Silk paint, (d) Eggshell paint, and (e) Gloss paint

Optical microscopy is an important first step when analysing paint, as it can assist in determining rudimentary features of paint, such as basic morphology and the defining number of paint layers and their thickness (Zieba-Palus, 1999: Stoecklein, 2001; Thoonen, et al., 2016). Prior to any in depth analysis of samples, the paint should first be examined using general microscopy, noting overall consistency of the surface structure and texture (De Forest, 2001; Wright, et al., 2011; SWGMAT, 2011). Portable microscopes (15x - 30x magnifications) can be used '*in situ*' at scenes to conduct preliminary paint analysis, however most samples are recovered and analysed in a laboratory, as this is where the majority of equipment and expertise are located (Welsh, 1982).

It is evident from Figure 24a that matt paint produced the most uneven and textured surface, showing a rough, coarse paint finish throughout the image. This is due to the high PVC of matt paints, causing a higher ratio of pigment particles to extend above the limited binder, providing scattered reflectance (Hansen, et al*.,* 1994; Ryland and Suzuki, 2012; Bender, 2013). Conversely, the gloss paint (Figure 24e) shows minimal texture due to the low PVC, as the majority of particles are secured below the binder film (*ibid*). However, it is not possible to establish the validity of this through optical microscopy, as a higher magnification is needed, as discussed in section 3.3.2. (Hochleitner, et al*.,* 2003).

The other paint types shown in Figure 24 (i.e. bathroom, silk and eggshell) show some similar properties to that of matt paint, as there is some evidence of texture, but it is not as pronounced. These visual images reflect the PVC levels described by the Paint Quality Institute (2004), who stated that silk paint has a PVC of 35% and eggshell paint at 35-45%, compared to gloss at 15% and matt paint which ranges between 38-80%; a level beyond CPVC, as noted in section 1.1.1. (Feller and Kunz, 1981).

Therefore, even at this early stage of analysis, it is possible to determine that there is a difference in paint topography. This will have an effect on the recovery of fingermarks, as the texture or smoothness of a surface has a significant effect on the deposition, and subsequent processing of latent marks, as discussed in section 2.4.3.3. (Jones, et al*.,* 2010; Yamashita and French, 2011; Bandey, et al*.,* 2014; Cadd, et al*.,* 2015). Therefore, it is important to explore paint topography in much greater detail using SEM (Hochleitner, et al*.,* 2003).

3.3.2. SEM and SEM-EDX analysis of paint samples

3.3.2.1. SEM – 500x magnification of different paint types

SEM was used to view each paint sample at 3 different magnifications (500x, 5,000x and 25,000x) to ascertain subtle and distinct differences between the 5 paint types (matt, silk, bathroom, eggshell and gloss). Figure 25 shows that at 500x magnification there are obvious structural differences between the paint types, particularly with matt paint.

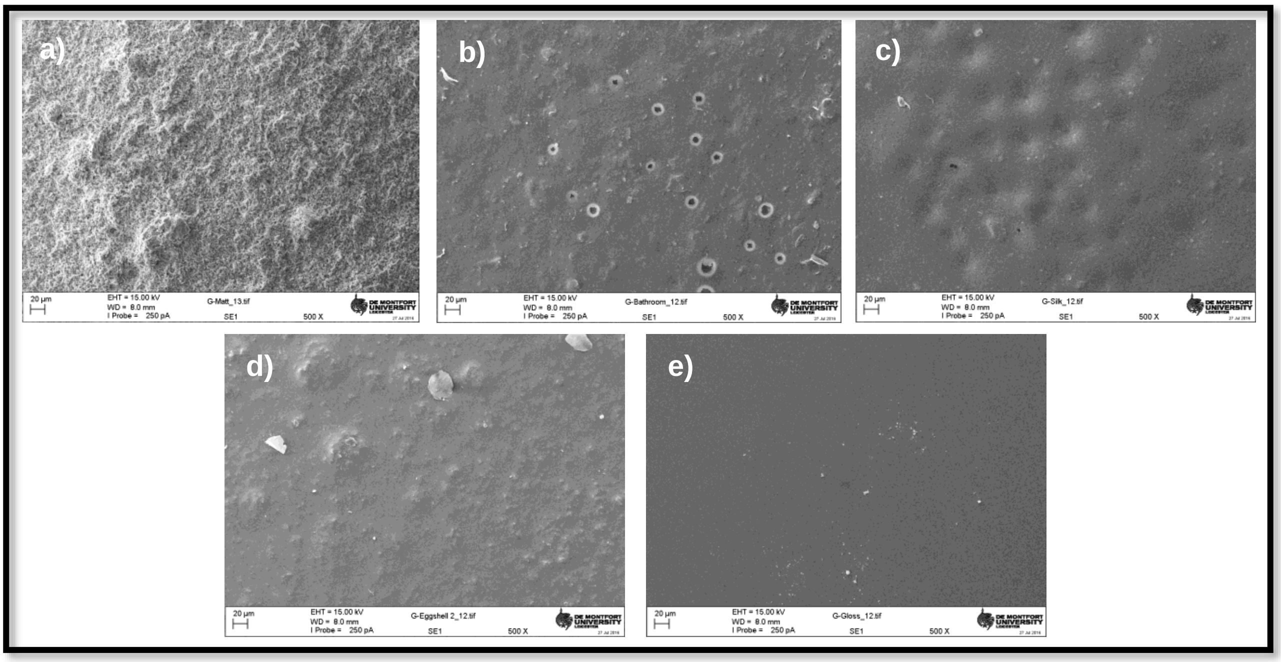


Figure 25 - SEM images at 500x magnification of (a) Matt paint, (b) Bathroom paint, (c) Silk paint, (d) Eggshell paint, and (e) Gloss paint

SEM is more informative than optical microscopy, as it has approximately 300 times greater depth of field, which allows for more extensive analysis to be carried out on areas that are as little as a few μm^2 (Van Essen, 1974; Ramotowski, 2013e). Therefore, the purpose of using SEM in this study was to visualise individual particles within paint samples and to determine the overall structure of the dried paint film, as per SWGMAT guidelines (2002). The combination of SEM and EDX allows for both elemental and surface properties to be collated and investigated (Sciutto, et al*.,* 2014), which will assist in exploring the relationship between paint topography and fingermark deposition, and clarify why such results were obtained in Chapter 2.

The results presented in Figure 25 show that at 500x magnification gloss paint appears smooth, with only a small number of irregular particles visible. This is attributable to the low PVC (~15%) of gloss paint (Tiarks, et al*.,* 2002; Resene, 2003; Paint Quality Institute, 2004). Conversely, silk, bathroom and eggshell paints all show some texture to the surface, which is characteristic of paints with a slightly higher PVC (~35-45%) (Paint Quality Institute, 2004). Both silk and bathroom paints show some circular stippling marks on the surface. This is due to air bubbles created when the paint was applied with a roller over the porous plasterboard (Guy, 2004; Dulux, 2015b). The imperfections noted in silk and bathroom paints could have an effect on the deposition of fingermarks, as the finger may not make full contact with the surface, due to gaps formed by air bubbles, producing discontinuous ridge detail in any processed fingermarks (Yamashita and French, 2011; Kent, 2013a). This outcome would produce partial fingermarks, which could be unattributable to a specific individual, leaving the marks unidentified.

However, the topography of matt paint is noticeably different, as it is irregular and unevenly textured. This is due to the higher pigment to binder ratio (~38-80% PVC), which produces a powdery appearance (Hansen, et al*.,* 1994; Paint Quality Institute, 2004; Ryland and Suzuki, 2012; Bender, 2013).

This will also have an effect on the deposition of fingermarks, as rough, uneven surfaces do not allow for full contact to be made with the surface, resulting in the deposition of partial marks (Kent, 2013a; Bandey, et al., 2014). Whilst it is possible to determine morphological disparities at 500x magnification, it is important to explore the surface configurations of the paint at a higher magnification to establish further differences which may explain the results presented in Chapter 2.

3.3.2.2. SEM – 5,000x magnification of different paint types

The same samples were viewed again under a higher magnification to assess the topography of the paints, allowing for similarities and differences to be visualised. Figure 26 displays the SEM images of the studied paint types at 5,000x magnification, which shows distinct differences between the paint structure of matt compared to the other four non-matt paints.

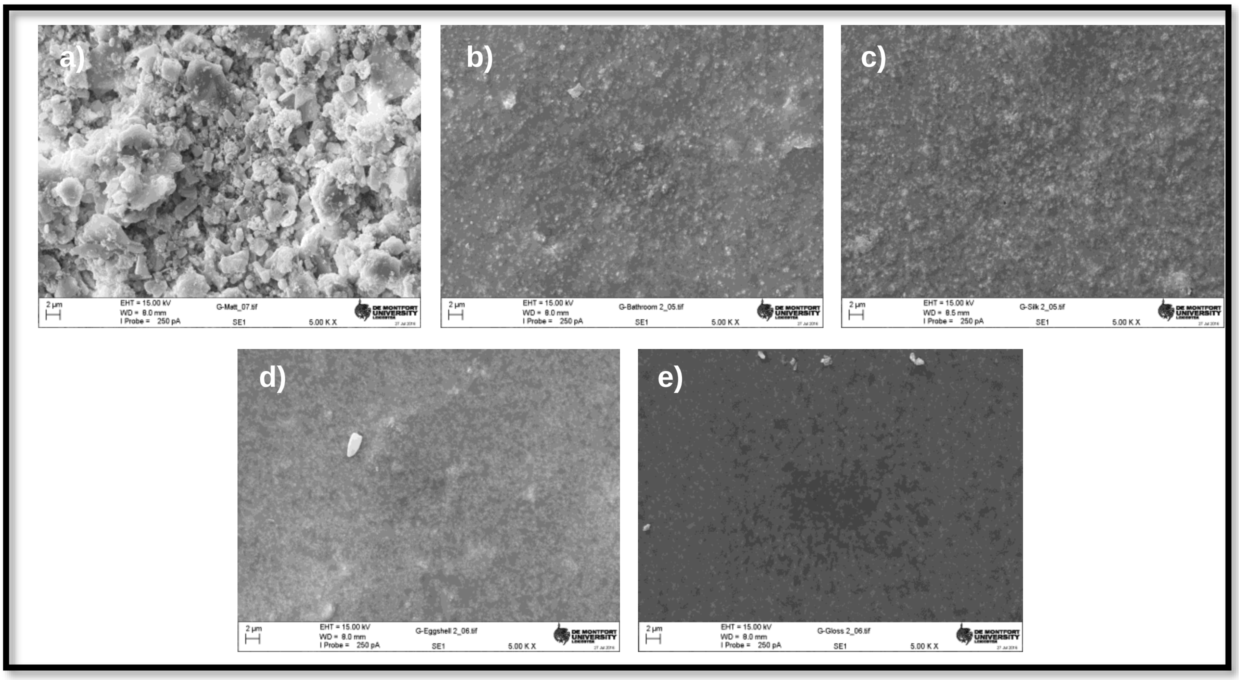


Figure 26 - SEM images at 5,000x magnification of (a) Matt paint, (b) Bathroom paint, (c) Silk paint, (d) Eggshell paint, and (e) Gloss paint

At 5,000x magnification it is possible to observe particle distribution on the surface (Kugge, et al*.,* 2004). In the sample of gloss paint (Figure 26e) it is clear that the particle size and distribution is homogeneous throughout the binder layer. This is important in terms of paint finish, as the uniform size and dispersion of the particles reduces the frequency of particle overlap, which allows for better reflection – creating a shiny gloss finish (Braun, 1995). Bathroom, silk and eggshell paints also demonstrate a relatively consistent dispersion of particles throughout the samples however, unlike gloss, the pigments are not all contained within the binder layer, as can be seen in Figure 26b-d. Nevertheless, the paints appear uniformly smooth, which is beneficial for the deposition and subsequent development of latent fingermarks, as this allows for the full finger to make contact with the surface producing continuous ridge detail (Bandey, et al*.,* 2014)

Conversely, the topography of matt paint is very different to the others, as shown in Figure 26a. The particles are irregular and unevenly distributed throughout the sample, presenting a rough and textured surface. The particles also appeared to be layered; some being attached to the binder layer with others being connected to other particles. This outcome reflects the findings of other studies that discuss the protrusion of pigment particles above the binder within high PVC paints, such as matt (Hansen, et al*.,* 1994; Ryland and Suzuki, 2012; Bender, 2013). The surface structure of the paint has a considerable effect on its functional properties. As the roughness and texture of the surface increases, the stress distribution, adhesion and durability decreases (Resene, 2003; Najjar, et al*.,* 2006). This will have a significant impact on the deposition of latent fingermarks on matt painted walls, as only partial ridge detail may make contact with the rough, textured surface, making it impossible to recover a full fingermark (Kent, 2013a; Bandey, et al*.,* 2014). This was highlighted in the various preliminary studies of this research (Chapter 2), where only a limited number of fingermarks were recovered from matt painted surfaces; most of which were of poor quality.

By examining the paint types at 5,000x magnification it was possible to determine some of the key differences between the paints, assisting in the explanation of the results presented in Chapter 2. However, it is prudent to examine these differences more closely to fully understand the relationship between paint type and fingermark deposition.

3.3.2.3. SEM – 25,000x magnification of different paint types

The same samples were viewed again at a higher magnification to assess pigment size and shape, as well as the overall topography of the paints. Figure 27 displays the SEM images of the paint types at 25,000x magnification, which shows similarities between pigment size and distribution in bathroom, silk, eggshell and gloss paints, but a distinctive difference in matt paint.

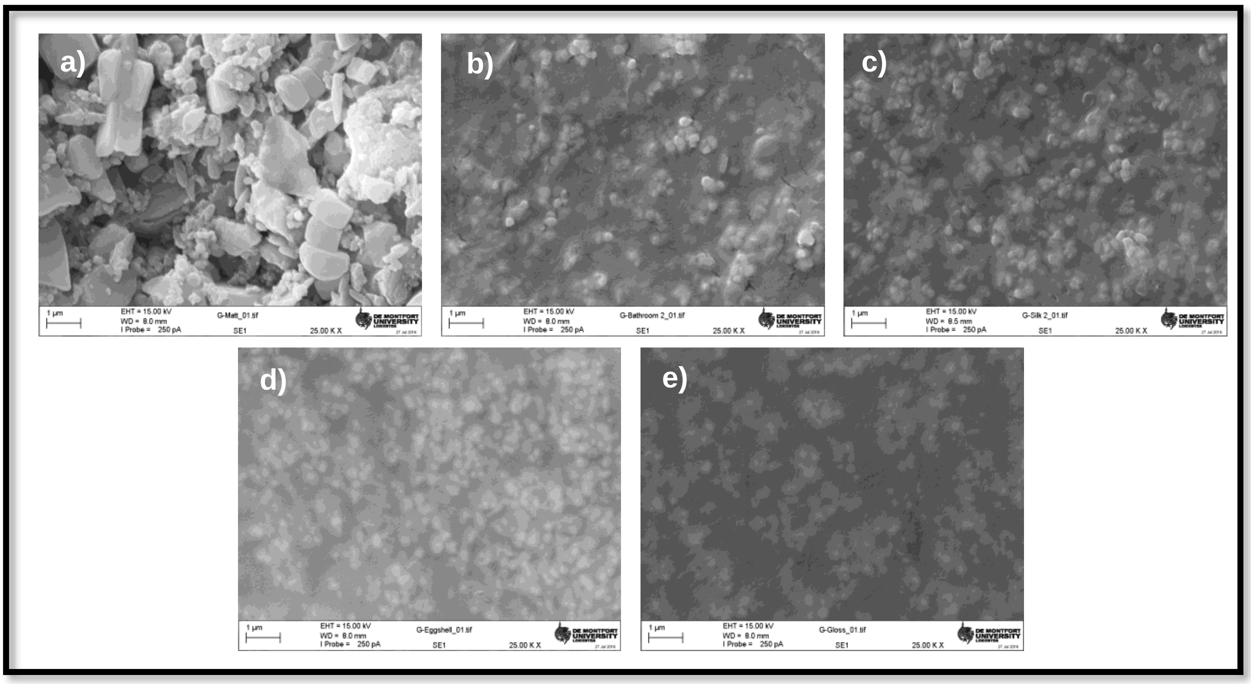


Figure 27 - SEM images at 25,000x magnification of (a) Matt paint, (b) Bathroom paint, (c) Silk paint, (d) Eggshell paint, and (e) Gloss paint

When viewing the images in Figure 27 it is apparent that the particles found within matt paint are considerably different in size and shape compared to the other paint types. Particle size and shape has a considerable effect on the hiding power of the paint, along with the refractive index of both the binder and the pigments (Gueli, et al*.,* 2017). Pigment particles can generally be categorised into three groups; fine, medium and coarse. 'Coarse' particles consist of pigments that have a diameter >10 μm, whereas 'medium' particles are smaller with a diameter of between 1-10 μm. Consequently 'fine' particles are defined as having a diameter <1 μm (*ibid).* In order to ascertain whether or not matt paint should be categorised differently to the other paint types it is necessary to compare the size of the particles that are visible in each of the SEM images presented in Figure 27. The results of which are presented in Table 22 below.

Table 22 - Analysis of mean particle sizes (± standard deviation) and range of particle sizes (N=10) of different paint types (matt, silk, bathroom, eggshell and gloss)

Paint Type	Mean Particle Length (μm) (± St Dev)	Range of Particle Lengths (μm)	Mean Particle Width (μm) (± St Dev)	Range of Particle Widths (μm)
Matt	0.87 (± 0.61)	0.21 – 2.09	0.78 (± 0.60)	0.18 – 2.09
Silk	0.29 (± 0.05)	0.22 – 0.37	0.28 (± 0.06)	0.21 – 0.38
Bathroom	0.32 (± 0.09)	0.18 – 0.45	0.32 (± 0.08)	0.19 – 0.45
Eggshell	0.28 (± 0.05)	0.21 – 0.36	0.28 (± 0.04)	0.21 – 0.33
Gloss	0.28 (± 0.02)	0.23 – 0.32	0.28 (± 0.04)	0.22 – 0.34

The measurements displayed in Table 22 show that the mean particle size (both length and width) for all paint types are <1 μm, thus placing them into the 'fine' category of particles (Gueli, et al*.,* 2017). However, when taking the range of particle sizes into consideration, some of the pigments found within matt paint were >1 μm (the largest measuring a length of 2.09 μm), classifying these as 'medium' particles (*ibid*). The range of particle lengths can be visualised in Figure 28, and range of particle widths in Appendix 3.

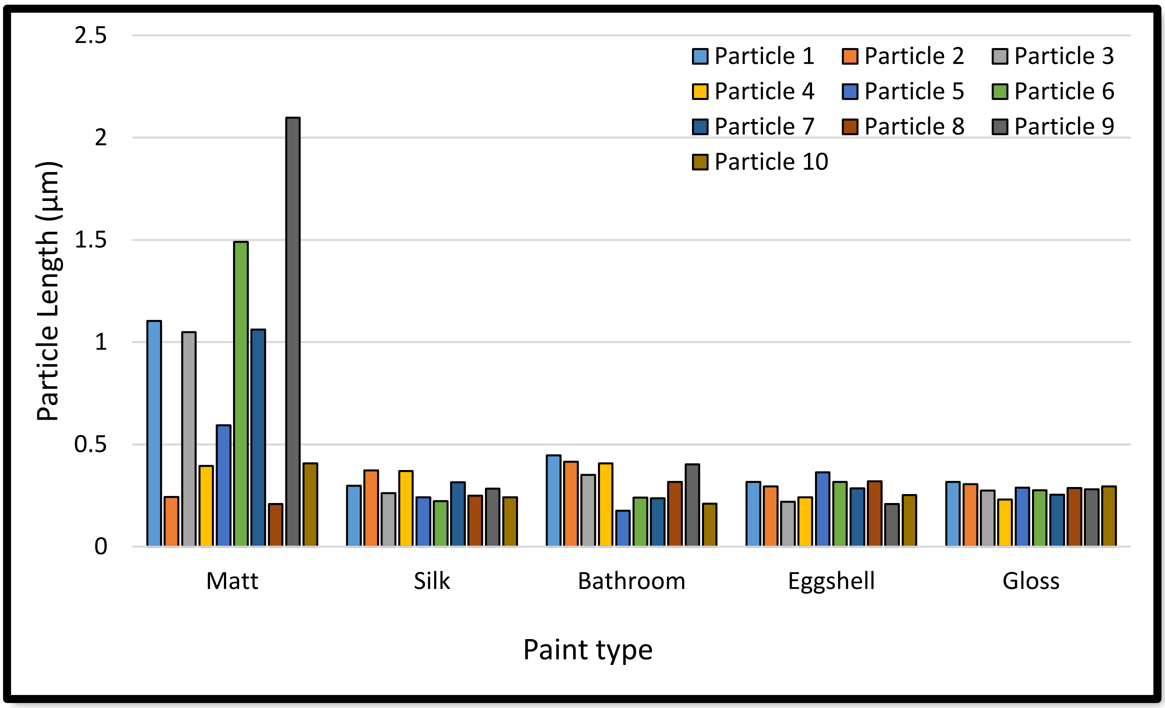


Figure 28 - Chart comparing the range of particle sizes (length) from different paint types

In order to ascertain whether or not the results presented in Figure 28 are statistically significant from each other, the Kruskal-Wallis test was applied to the non-parametric data. When testing whether there was a statistical difference between all of the different paint types, a p value of <0.05 was obtained showing that the length of particles within the different paint types are significantly different at a 95% confidence level. However, as Figure 28 shows, the range of particle sizes amongst silk, bathroom, eggshell and gloss paints are not as discernible from each other, compared to matt. When applying the Kruskal-Wallis test to these four paint types only, a p value of 0.85 was returned, showing that the particle sizes of these paints were not statistically significantly different from each other at a 95% confidence level. This shows that the particle sizes in non-matt paints, such as silk, bathroom, eggshell and gloss, are relatively uniform, whereas matt paints have considerably different particles sizes. This will not only affect the overall texture of the painted surface, but the subsequent quality of fingermarks which may be deposited onto a matt painted surface.

Paints, such as gloss and eggshell, are composed of small particles of a consistent size, in order to produce a finished surface with a high sheen. Therefore, these paints should only contain fine pigments (<1 μm but preferably <0.5 μm), as larger particles decrease the lustre of the paint (Becker and Bress, 1964*;* Braun and Fields, 1994). Table 22 and Figure 28 show that the range and average particle size within the silk, bathroom, gloss and eggshell paints used in this study are well within this specification. The constituents are uniformly small and equally dispersed in the binder, therefore the paint will appear homogeneous with a smoother non-porous finish (Horiba Scientific, 2012*;* Gueli, et al*.,* 2017).

However, there is a subtle difference between bathroom and silk paints compared to eggshell and gloss paints. When observing Figure 27d and e, it is apparent that the pigments are embedded well within the binder layer, without any protrusion. However, when examining Figure 27b and c, it is noticeable that not all of the pigments are embedded within the binder layer and some have extended above. Protruding pigments produce a visually inhomogeneous, more textured paint with poor hiding power (Horiba Scientific, 2012*;* Gueli, et al*.,* 2017).

However, others claim that it is the more textured, irregular pigmented paints that have increased hiding power, as light is reflected from the particles and scattered in several directions (Strauch, 2001; Gunde, et al*.,* 2006). Paint practitioners argue that paints with higher PVC, such as matt, are able to hide imperfections in walls more easily, regardless of pigment size (Resene, 2003; Paint Quality Institute, 2004). Nevertheless, all studies are in agreement that paints with higher PVC generally contain larger pigments, which means that the glossiness of the paint diminishes, and thus the paints are more porous and textured (Braun and Fields, 1994; Strauch, 2001; Guy, 2004; Gueli, et al*.,* 2017).

As described in Chapter 1, paints with higher PVC also have decreased 'scrubbability' making them more porous (Strauch, 2001; Najjar, et al*.,* 2006). As Figure 27 shows, matt paint is very textured, owing to high PVC content, making it a porous substrate. However, the precise height of the particle protrusions could not be established using SEM in this research. The texture and porosity of a painted wall are key factors to consider when establishing a fingermark recovery strategy for crime scenes (Jones, et al*.,* 2010; Yamashita and French, 2011; Cadd, et al*.,* 2015). If the topography of a painted wall is particularly rough and textured, then only a small proportion of ridge detail from a finger would make contact with the upper surface of the wall – regardless of how much pressure is applied. Thus, an incomplete mark would be deposited, rendering it impossible for either a CSE or a FLO to develop and recover a complete fingermark (Yamashita and French, 2011; Kent, 2013a; Bandey, et al*.,* 2014).

Substrate porosity is also a primary consideration when forming a fingermark recovery plan. If latent marks are deposited onto porous surfaces, then the water-soluble constituents migrate into the substrate itself, leaving the few remaining water insoluble components on the surface (Jasuja and Singh, 2009; Bandey, et al*.,* 2014). It is therefore vital that the methods used on porous surfaces are also absorbed into the substrates in order to react with the soluble constituents present (Daluz, 2015).

However, conflicting results were obtained and presented in Chapter 2, showing that ninhydrin is not effective on matt paints, which was unexpected given that it is a widely used, and well-evidenced process for porous substrates (Yamashita and French, 2011; Bleay, et al*.,* 2013; Bandey, et al*.,* 2014). This may be due to the lack of cellulose contained within the paint, which is known to affect the development of latent marks (Spindler, et al., 2011; Bleay, et al., 2017; Nicolasora, et al., 2018b). Fingermarks that are absorbed into cellulose materials are generally more stable, and therefore marks can be developed more effectively (Champod, et al., 2004; Hansen and Joullié, 2005; Daluz, 2015).

Surprisingly, non-porous processes, such as black magnetic granular powder, were shown to be more successful; the reasons for which are unknown and cannot be explained using microscopy alone. Nevertheless, none of the techniques previously tested in this study were efficient at developing latent marks on matt paint, which is, in all probability, due to the highly textured surface of the painted substrate, preventing full fingermark deposition (Bentley, 2001; Henson and Jergovich, 2001; Guy, 2004). Consequently, this novel research is vital in addressing this gap in knowledge, the results from which will provide evidence-based information to practitioners working '*in situ'* at crime scenes. This will therefore assist both FLOs and CSEs in validating particular processes for use on painted substrates as per the requirements for ISO 17020 and/or 17025 accreditation.

3.3.2.4. SEM/EDX of different paint types

Whilst analysing the various paint types using SEM, it was also possible to assess the elemental composition of the paints using SEM-EDX, to ascertain whether or not this may have an effect on the deposition and development of fingermarks on painted walls. Samples of the five main paint types (matt, silk, bathroom, eggshell and gloss) were analysed using SEM-EDX and are presented in Table 23.

Table 23 - Elemental composition of paint types (N=3) (C=Carbon, O=Oxygen, Na=Sodium, Mg=Magnesium, Al=Aluminium, Si=Silicon, Ca=Calcium, Ti=Titanium, Fe=Iron) (- not detected)

	Average weight %								
Paint	**C**	**O**	**Na**	**Mg**	**Al**	**Si**	**Ca**	**Ti**	**Fe**
Matt	22.35	38.63	0.32	0.39	-	0.27	23.46	6.29	8.29
Silk	37.52	32.80	0.39	-	1.72	1.99	0.35	20.00	5.22
Bathroom	34.67	31.96	-	-	3.38	4.53	-	25.45	-
Eggshell	34.56	33.31	-	-	0.86	1.02	1.37	28.88	-
Gloss	44.82	27.85	-	-	0.66	0.52	0.32	23.01	2.82

It is possible to observe some similarities in the results between all paint types. For example, all 5 paint types show <1% sodium and magnesium, and low amounts (<9%) of silicon, aluminium and iron. In addition to this, all 5 paint types show similarly higher levels of oxygen (20-50%). However, there are some distinct elemental differences between the 5 paint types as well. Titanium is a primary example of this, as matt paint only has an average of 6.29%, whereas the level is much higher in the non-matt paints (20.00-28.88%). Titanium dioxide is well known to be one of the most commonly used pigments in paint, due to its coverage ability and high refractive index, however it is also one of the most expensive components of paint (Ryland and Suzuki, 2012; Karakaş, et al*.,* 2015; Karlsson, et al*.,* 2015). Therefore, it is commonplace for paint manufacturers to supplement the mixture with extenders and additives, such as calcium carbonate, to increase the solid content of the paints and act as 'flatting agents' to reduce the sheen of the paint (Clark, et al*.,* 2002; Petraco and Kubic, 2003). This is evident when examining Table 23, as matt paint contains high levels of calcium (23.46%) compared to the other paint types (<2%). This elemental detail assists in explaining why matt paint has considerable different particle sizes and shapes, compared to the other paints, as it contains a large quantity of extenders, such as calcium carbonate, and only a small amount of titanium dioxide pigments (Clark, Wansbrough, and Lipsham, 2002; Bender, 2013). Whereas other non-matt paint types do not contain large quantities of extenders, and therefore the particles are more uniform in shape and size, as shown in Figure 31.

However, it is important to note that the elemental composition has little effect on the deposition and development of fingermarks on painted walls, as it is the overall topography of the paint that is the most significant factor for success, as detailed in the SEM images. Nevertheless, it is not clear whether the morphology of all matt paints are similar, as the studies discussed in Chapter 2 (sections 2.4.2. and 2.4.3.) regarding different brands of matt paint showed conflicting results. Therefore, it is necessary to explore the surface structure of various brands of matt paint to ascertain why these results may have occurred.

3.3.2.5. SEM – 25,000x magnification of different matt paints

The same brands of matt paint used in previous studies (Chapter 2), as stated in Table 20, were sampled and viewed under a high magnification to assess pigment size and shape, as well as their overall topography. Figure 29 displays the SEM images of the different matt paints at 25,000x magnification, illustrating many parallels in pigment size and distribution throughout the samples.

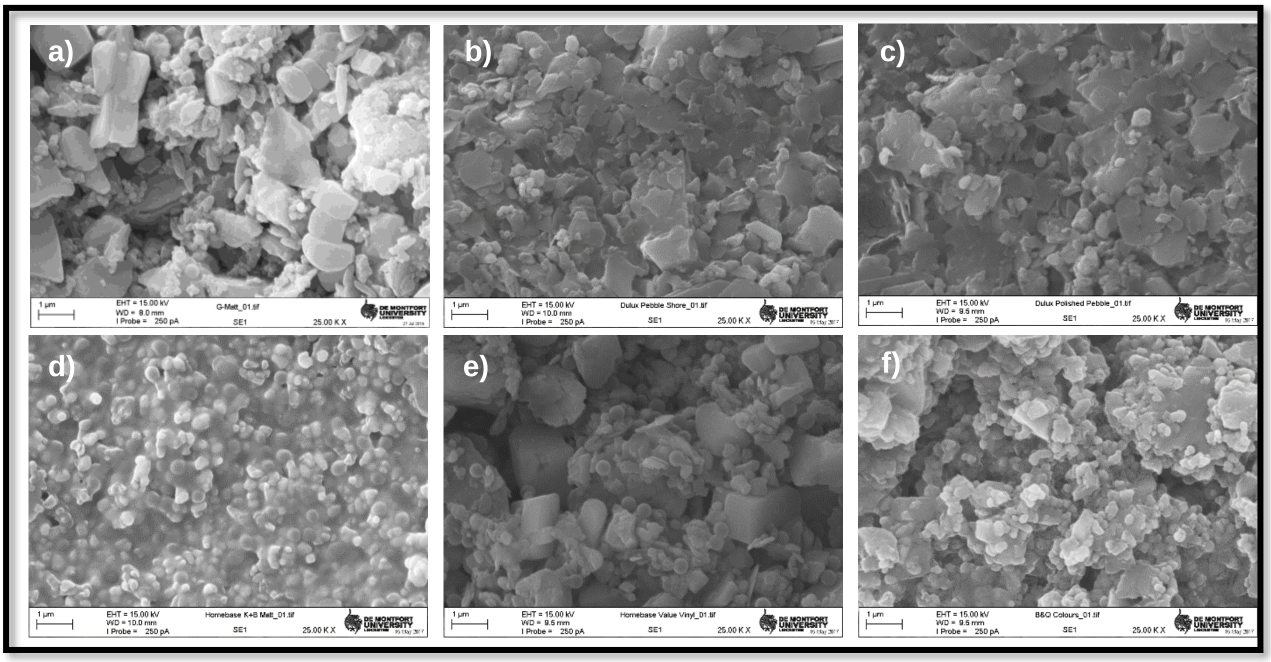


Figure 29 - SEM images of matt paints at 25,000x magnification, specifically (a) Wickes Trade, (b) Dulux 'Pebble Shore', (c) Dulux 'Polished Pebble', (d) Homebase Kitchen and Bathroom, (e) Homebase Value Vinyl, and (f) B&Q Colours

As Figure 29 displays, the different matt paints appear to be similar, in terms of particle distribution, apart from Figure 29d – Homebase kitchen and bathroom matt paint. It is possible to observe a wide range of particle sizes and shapes within the matt paints; the majority of which are extending high above the binder layer. These findings are in accordance with previous research which examined the protrusion of pigment particles within high PVC paints, producing a rough and textured surface, which is porous (Hansen, et al*.*, 1994; Resene, 2003; Najjar, et al*.*, 2006; Ryland and Suzuki, 2012; Bender, 2013).

However, such paints do not only contain pigment particles, but also extenders (i.e. calcium carbonate) and additives (i.e. fungicides) as well (Bentley, 2001). The additional extender particles increase the roughness and texture of the dried paint film, which assists in scattering light and providing a matted finish (Bentley, 2001; Henson and Jergovich, 2001; Guy, 2004). This assists in explaining the quantity and distinctive differences in particle sizes and shapes found within Figure 29. Consequently, when designing a fingermark recovery plan for matt painted surfaces, it should be necessary to use porous development processes, such as ninhydrin, which are already recommended for matt painted substrates (Bandey, et al*.,* 2014). Contradictory to this, previous results in this study (discussed in Chapter 2) have shown that ninhydrin is not effective on matt paints, with non-porous processes, such as black magnetic granular powder, providing more successful results. Regardless, none of the 3 processes used in the preliminary tests were particularly effective on matt paint, which is most likely due to the highly textured topography of the painted surface, as shown in Figure 30, preventing full initial fingermark deposition and trapping particles of powder (Bentley, 2001; Henson and Jergovich, 2001; Guy, 2004).

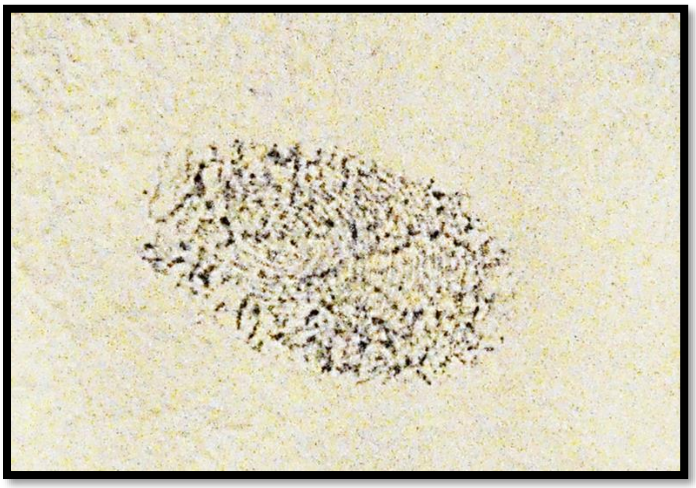


Figure 30 - Image of fingermark in black magnetic granular powder on matt paint

Conversely, Figure 29d reveals a different style of paint with particles that are more uniform in shape and size. This paint appears more in accordance with non-matt paints, such as silk, which have a lower PVC (Paint Quality Institute, 2004). This finding explains the results in Table 18 (Chapter 2) regarding the higher number of fingermarks that were recovered from Homebase kitchen and bathroom matt paint (34% of total deposited fingermarks) compared to other matt paints (which ranged between 7-24% of total marks deposited). When compared against other silk paints, not only does Homebase kitchen and bathroom matt paint appear visually similar in the SEM images, it also responded to fingermark deposition and processing in a similar way, as both Wickes trade vinyl silk and Dulux silk both developed 38% and 37% of total deposited fingermarks respectively. It is therefore pertinent to explore whether or not there are differences between an assortment of non-matt paints to ascertain why there were such variations in the results presented in Chapter 2.

3.3.2.6. SEM – 25,000x magnification of different non-matt paints

The same brands of non-matt paint used in previous studies (Chapter 2), as stated in Table 20, were sampled and viewed under a high magnification to assess pigment size and shape, as well as their overall topography. Figure 31 displays the SEM images of the different non-matt paints at 25,000x magnification, illustrating many similarities between pigment size and distribution throughout the samples.

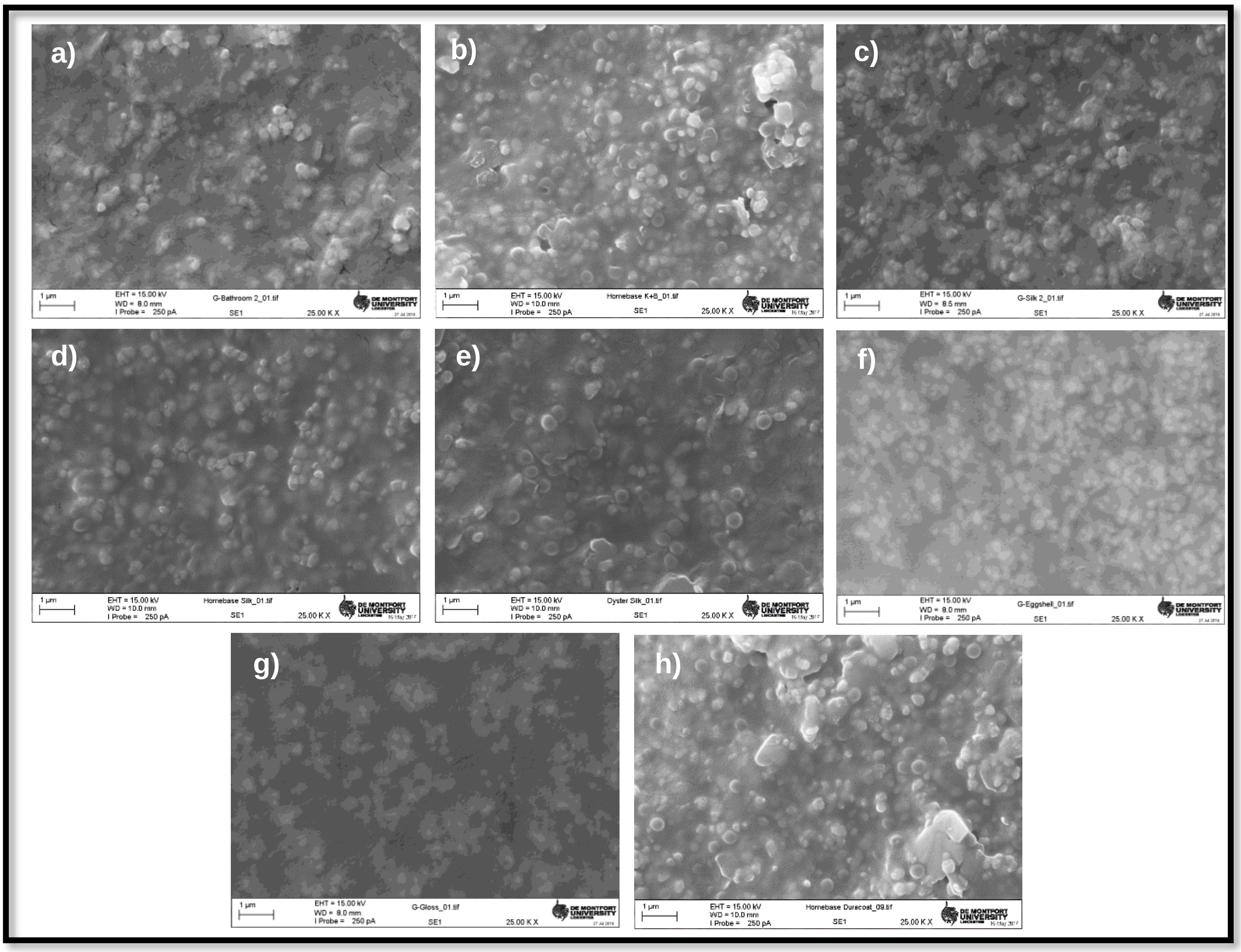


Figure 31 - SEM images of non-matt paints at 25,000x magnification, specifically (a) Wickes ‘Colour at Home’ Bathroom, (b) Homebase ‘Home of Colour’ Kitchen and Bathroom, (c) Wickes Trade Vinyl Silk, (d) Homebase Silk, (e) Dulux ‘Almost Oyster’ Silk, (f) Wickes Trade, (g) Homebase Gloss, and (h) Homebase ‘Home of Colour’ Duracoat

As Figure 31 displays, the different non-matt paints appear to be very similar, showing uniform particles of comparable size and shape, as expected in paints with a higher sheen (Becker and Bress, 1964*;* Braun and Fields, 1994). This shows that these paints will be much smoother in texture, compared to matt paints, and should provide a non-porous finish (Horiba Scientific, 2012*;* Gueli, et al*.,* 2017).

However, as discussed earlier, there is a difference between the eggshell and gloss paints (Figure 31f and g) compared to the other non-matt paints. These two paints in particular show that the pigments are fully immersed in the binder layer, making it difficult for the particles to be visualised within the images. As the binder encloses the pigments, the final dried painted film will produce a non-porous finish (Horiba Scientific, 2012*;* Gueli, et al*.,* 2017). Therefore, when creating fingermark recovery strategies for scenes involving gloss or eggshell painted surfaces, it will be necessary to use non-porous development techniques, such as powders or powder suspension. This is already recommended for gloss painted substrates (Bandey, et al*.,* 2014), and therefore the results in this chapter show that the same processes should also be recommended for eggshell painted surfaces as well. However, the type of paint that has been applied to a wall is not always clear to practitioners (as highlighted in the questionnaire – section 2.2.2.2.), and therefore it may be difficult to distinguish between non-porous paints (i.e. gloss/eggshell) and other semi-porous or porous paints. Thus, it may be pertinent to develop a methodology to determine the differences between paint types that can be used by practitioners '*in situ*' (as discussed in section 3.3.3.).

The results presented in Chapter 2 show that powders, especially black magnetic granular, are efficient in developing marks on eggshell paint, thus proving the validity of this recommendation. Conversely, other non-matt paints, such as silk, kitchen, bathroom and Duracoat, will dry with a semi-porous finish. This is due to a number of particles extending slightly above the binder layer, as visible in Figure 31, which will decrease the lustre of the paint somewhat (Becker and Bress, 1964*;* Braun and Fields, 1994). Sequential processing combining both porous and non-porous techniques is already recommended for silk painted substrates (Bandey, et al*.,* 2014), which could further be extended to incorporate kitchen, bathroom and Duracoat style paints.

The results displayed in Chapter 2 show that powders are effective in developing marks on these paint types, and can be applied by both CSEs and FLOs, thus providing a rationale for such a recommendation. Nevertheless, it is pertinent to specify the type of powder to be used, ensuring that practitioners are applying black magnetic granular powder, rather than another powder type, such as magneta flake powder, which is not effective on painted walls, as discussed in Chapter 2.

However, ninhydrin also showed some good results on silk paint, and therefore it may be pertinent to include ninhydrin in guidelines for practitioners, as this is not recommended at present. This will increase the possible yield of fingermarks recovered from crime scenes and will detect latent marks that are rich in eccrine deposits (using ninhydrin), as well as sebaceous deposits (using other methods) (Daluz, 2015). Nevertheless, it is important to note that only FLOs are able to utilise ninhydrin *'in situ'* and therefore this process is only likely to be used at serious and major crime scenes.

Nevertheless, these findings do not assist in explaining why a significantly higher number of fingermarks were developed on Homebase silk painted walls, as shown in Table 18 (Chapter 2) compared to other semi-porous and non-porous paint types (although gloss paint was not included in these studies). The morphology and topography of this paint does not appear different to the other silk paints; therefore, it is pertinent to explore the size of the particles within the matt and non-matt paints to ascertain whether or not this is a significant factor in the deposition and development of fingermarks.

3.3.2.6. SEM – Comparison of particle sizes in matt and non-matt paints at 25,000x magnification

The images in Figure 29 and Figure 31 were analysed further and a random selection of particles (N=10) were measured (both length and width) in each paint type/brand, the results of which are presented in Table 24.

Table 24 - Analysis of mean particle sizes (± standard deviation) and range of particle sizes (N=10) for different matt and non-matt paints

	Paint Type/Brand	Mean Particle Length (µm) (± St Dev)	Range of Particle Length (µm)	Mean Particle Width (µm) (± St Dev)	Range of Particle Width (µm)
Matt	**Wickes Trade Matt**	0.87 (± 0.61)	0.21 – 2.09	0.78 (± 0.60)	0.18 – 2.09
	Dulux 'Pebble Shore' Matt	0.74 (± 0.49)	0.15 – 1.49	0.62 (± 0.37)	0.19 – 1.09
	Dulux 'Polished Pebble' Matt	0.87 (± 0.71)	0.28 – 2.45	0.78 (± 0.50)	0.19 – 1.63
	Homebase Kitchen and Bathroom Matt	0.41 (± 0.08)	0.32 – 0.56	0.37 (± 0.07)	0.25 – 0.52
	Homebase Value Vinyl Matt	0.83 (± 0.75)	0.16 – 1.89	0.78 (± 0.59)	0.26 – 1.88
	B&Q Colours Matt	0.88 (± 0.81)	0.18 – 2.75	0.71 (± 0.68)	0.15 – 1.96
Non-Matt	**Wickes 'Colour at Home' Bathroom**	0.32 (± 0.09)	0.18 – 0.45	0.32 (± 0.08)	0.19 – 0.45
	Homebase 'Home of Colour' Kitchen and Bathroom	0.35 (± 0.04)	0.29 – 0.40	0.32 (± 0.04)	0.26 – 0.39
	Wickes Trade Vinyl Silk	0.29 (± 0.05)	0.22 – 0.37	0.28 (± 0.06)	0.21 – 0.38
	Homebase Silk	0.28 (± 0.07)	0.17 – 0.39	0.26 (± 0.03)	0.21 – 0.30
	Dulux 'Almost Oyster' Silk	0.32 (± 0.05)	0.23 – 0.39	0.32 (± 0.07)	0.20 – 0.41
	Wickes Trade Eggshell	0.28 (± 0.05)	0.21 – 0.36	0.28 (± 0.04)	0.21 – 0.33
	Homebase Gloss	0.28 (± 0.03)	0.23 – 0.32	0.28 (± 0.04)	0.22 – 0.34
	Homebase 'Home of Colour' Duracoat	0.35 (± 0.05)	0.30 – 0.47	0.36 (± 0.06)	0.27 – 0.46

As shown in Table 24, the range of particle sizes within the matt paint brands was vast (0.15 – 2.75 μm), whereas the particles for non-matt paints were much smaller and more uniform (0.17 - 0.47 μm). The average particle sizes for matt paints were also much larger (0.77 μm) compared to non-matt paints which were noticeably smaller (0.31 μm). The results for particle length are depicted in Figure 32, to enable direct comparisons to be made between matt and non-matt paints. The results for particle width are displayed in Appendix 3. It is evident from Figure 32 that the mean particle sizes are much larger for matt paints compared to non-matt paints. In addition to this, it is also clear that the range of particle sizes is much more varied in matt paints compared to non-matt paints.

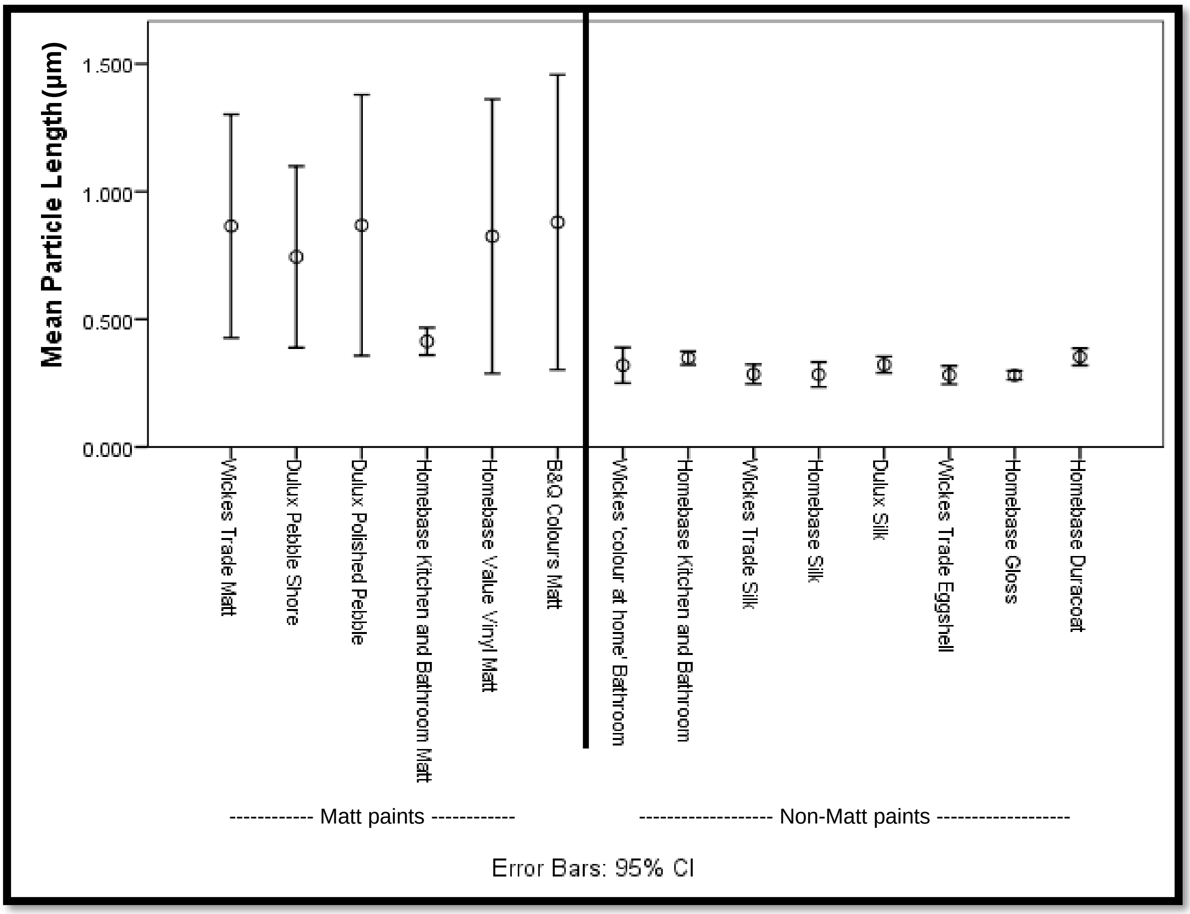


Figure 32 - Chart comparing particle sizes from different paint types and brands (N=140)

However, Figure 32 also highlights that Homebase kitchen and bathroom matt paint is constructed differently to other more general matt paints, as the mean particle size and range of particle sizes are more similar to those seen in non-matt paints.

This assists in explaining the results found in Chapter 2, where more fingermarks were recovered from Homebase kitchen and bathroom matt paint (and all non-matt paints) compared to general matt paints. If the particle sizes are smaller and more uniform, as displayed in Figure 32, then the painted surface will be smoother, allowing for optimal finger contact and full deposition of a mark. Whereas in other matt paints the particle sizes are more varied, producing a highly textured painted surface, which will prevent full finger contact (as shown in Figure 33) and therefore a disrupted mark will be deposited (Henson and Jergovich, 2001; Guy, 2004). Consequently, it is important to determine which paint type has been applied to the walls of a crime scene prior to utilising any development methods, as the paint type does have an effect on the topography of the surface.

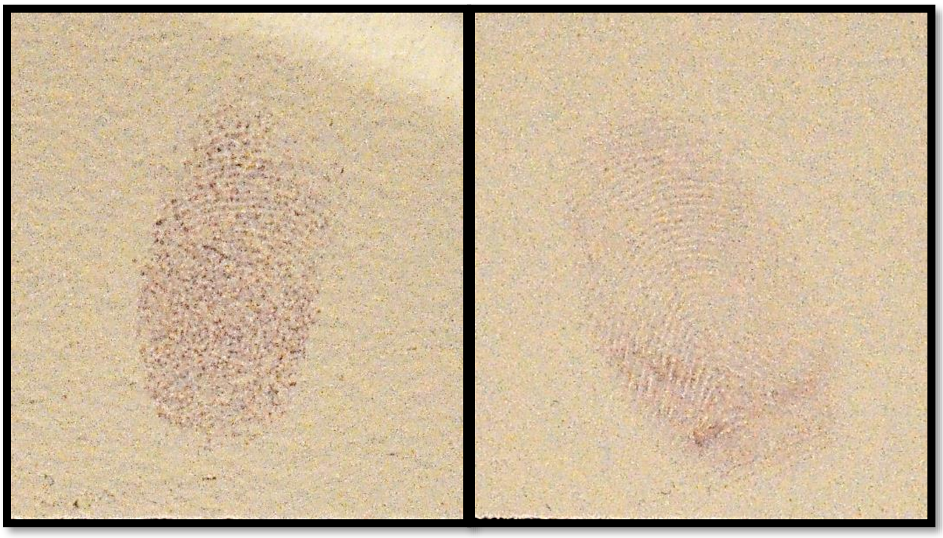


Figure 33 - Images showing the topographical effect on the development of fingermarks with ninhydrin, on Wickes Trade matt paint (left) and Homebase Kitchen and Bathroom matt paint (right)

3.3.3. Results from 'wipe tests'

In order to distinguish between differing paint types '*in situ*' at crime scenes, a simple, quick and cost-effective test is needed for practitioners, as discussed in section 2.2.2.2. There are a number of published methodologies to test various aspects of paints, including over 100 ASTM standards (ASTM, 2018). However, these require a range of instrumentation that CSEs and FLOs do not have, and as a result cannot be utilised '*in situ*' at scenes by fingermark practitioners.

Therefore, in order to fill this gap in knowledge, a series of tests were conducted using a range of cleaning materials that could be easily purchased with minimal cost implications. The materials were either kept dry, or moistened using water (labelled as 'wet'), ethanol or suspension solution, and then applied to the painted surfaces using differing motions, as described in section 3.2.3.3. These solutions were chosen as they are cheap and readily available to practitioners, although the flammability of ethanol must be carefully considered before using '*in situ*' (Bandey, et al., 2014; Bleay, et al., 2017). The aim was to identify a cleaning material and an application method that would be able to distinguish between matt and non-matt paints, on the basis of how much of the paint had been transferred to the cloth. This would provide practitioners with a quick, easy and cost-effective test that they could utilise on the wall to determine whether it was matt or non-matt paint, and then apply the correct set of sequential treatments to the painted wall.

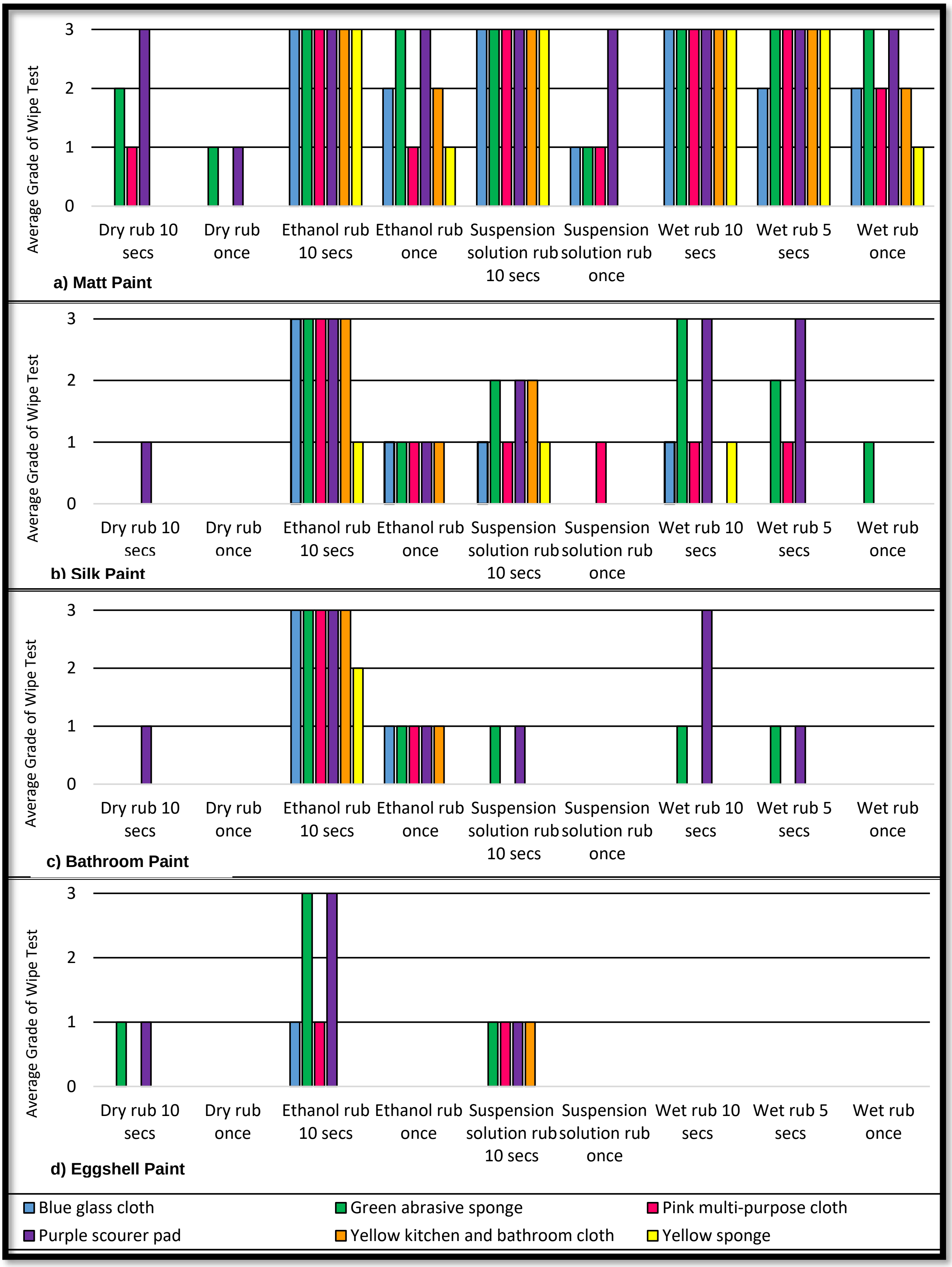


Figure 34 - Results of wipe tests on; (a) matt paint, (b) silk paint, (c) bathroom paint, (d) eggshell paint.

The tests were first conducted on the four most common paint types (matt, silk, bathroom and eggshell) (Wickes, 2015). The results (Figure 34) showed that a number of processes worked well on matt paint, with a large amount of paint being removed from the surface and adhering to the cloth (Figure 35). On the contrary, eggshell paint showed minimal results, with only abrasive cloths and those moistened with ethanol, showing any paint transfer. Both bathroom and silk paints had some success, but these were also more effective when used with solvents and abrasive cloths.

The data presented in Figure 34 was analysed to determine if any of the cleaning materials and application methods tested would allow practitioners to differentiate between the paint types. Overall the more abrasive the cloth, the more paint was transferred, which was noted across all paint types. Therefore, the purple scourer pad and green abrasive sponge are not suitable materials to be used in a presumptive paint test and were therefore eliminated from any further tests.

It was also clear that when moistening the cleaning materials using solvents, such as ethanol, all types of paint were more easily transferred from the wall to the cloth. This was unsurprising as ethanol is used in paint remover solutions, and therefore should ease the transfer of paint from the wall to the cloth (Grob and Barry, 2004). The results also revealed that the use of dry cloths was not productive, as there was an insufficient amount of paint transferred onto the cloth, regardless of paint or cloth type. This was unsurprising for non-matt paints, due to their lower PVC, which increases the adhesion of such paints (Resene, 2003). However, it was expected that there would be some transfer of matt paint onto dry cloths, due to the high PVC and lower adhesion properties (Strauch, 2001; Najjar, et al., 2006).

Figure 35 - Image showing transfer of matt paint when 'rubbed for 10 seconds' in a circular motion on yellow kitchen and bathroom cloth (left), and green abrasive sponge (right)

On the other hand, when the cleaning materials were moistened with water, the non-matt paint was less easily transferred. This is again attributable to the PVC levels being lower, thus the paint particles are more firmly appended to the binder layer, increasing its 'scrubbability' (Resene, 2003). The particles found within matt paint however, protrude significantly from the binder layer, as shown in Figure 29 and are therefore more easily detached from the wall and transferred to the cloth.

Therefore, the results for all water moistened materials (blue glass cloth, pink multi-purpose cloth, yellow kitchen and bathroom cloth, and yellow sponge) were examined in more detail to ascertain whether or not the application method could be used to distinguish between matt and non-matt paints. In terms of methodology, the longer the material was rubbed onto the surface, the more transfer was noted. However, if only rubbed once, the amount of paint transferred was minimal and inconsistent. Consequently, the most effective methodology was applying wet but soft materials which were rubbed in a circular motion for 5 seconds (with abrasive cloths having been eliminated from the analysis). Figure 36 shows that this particular methodology is discriminating and can distinguish between matt and non-matt paints.

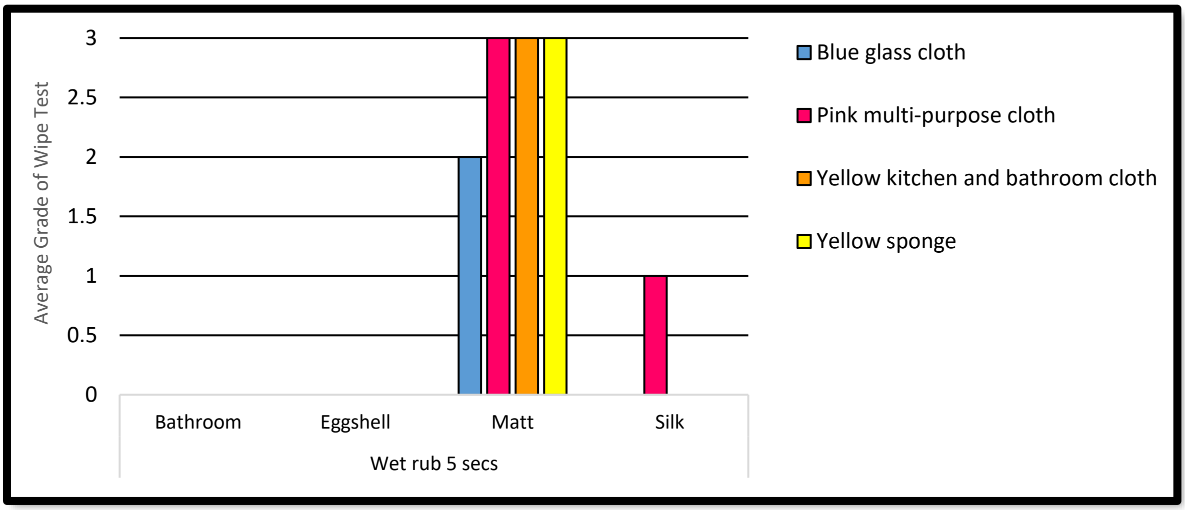


Figure 36 - Results of 'wipe test' involving wet soft cloths being rubbed for 5 seconds

When rubbing for 5 seconds, only three types of soft cloth (blue glass cloth, yellow kitchen and bathroom cloth and yellow sponge) showed any transfer of matt paint. No transfer occurred with silk, bathroom or eggshell paint using the same application methodology. Conversely, the pink multi-purpose cloth showed transfer of both matt and silk paint; although only a small amount of transfer was noted from silk paint. Nevertheless, the grading of paint transfer is very subjective, and therefore it would be difficult for practitioners to decide whether the displacement should be interpreted as being from matt paint or not. Therefore, the pink multi-purpose cloth was also eliminated.

Both the yellow kitchen and bathroom cloth and the yellow sponge provided reliable and consistent results using this methodology, allowing for matt paint to be differentiated, whereas the blue glass cloth was not as effective. Therefore, this cloth was eliminated from the study. The cheapest of these cleaning materials was the yellow sponge, which is widely available and can be purchased from the majority of supermarkets and smaller local shops. Therefore, this sponge was examined in more detail (Figure 37) to test different brands of matt and non-matt paint.

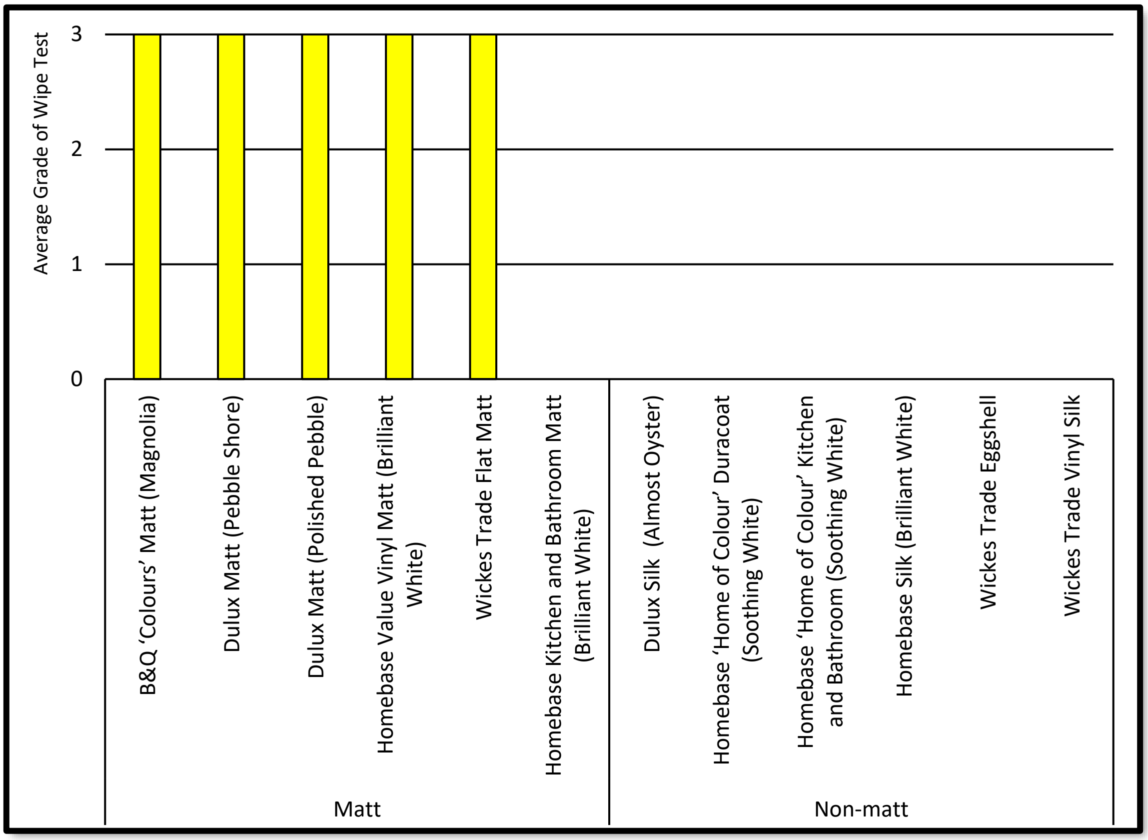


Figure 37 - Results of 'wipe test' involving wet yellow sponge being rubbed for 5 seconds on matt and non-matt paints

As Figure 37 shows, the wet yellow sponge, rubbed in a circular motion for 5 seconds, was an effective presumptive test to differentiate between matt and non-matt paint, with the exception of Homebase kitchen and bathroom matt. This result is consistent with the findings reported in Chapters 2 and 3, where Homebase kitchen and bathroom matt paint differed from other matt paints. In general, it behaves like a non-matt paint, with a significantly larger amount of fingermarks being recovered from it when compared to matt paints (as discussed in sections 2.4.3.). In addition to this, Homebase kitchen and bathroom matt paint is also constructed as if it was a non-matt paint, with smaller consistently sized particles, as shown in Figure 29. Therefore, although the paint is labelled as a matt paint, the wipe test was correct in deeming it to be a non-matt paint and should be treated as such.

Not only did the different brands of matt paint transfer to the sponge, but there was also visible evidence of paint disturbance left behind. This did not happen with other paint types, as there was no paint adhesion on the sponge and there were no signs of visible disturbance left on the paint itself (Figure 38). Therefore, the presumptive test that should be recommended for use by both CSEs and FLOs is a yellow sponge, moistened with water and rubbed in a small circular motion for 5 seconds.

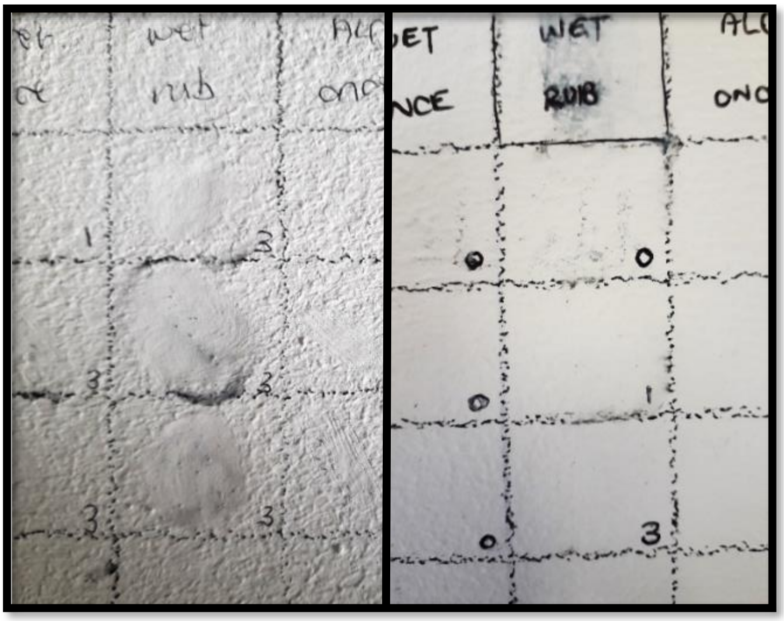


Figure 38 - Image showing visual differences between results of wet yellow sponge 'rubbed for 10 seconds' on matt paint (left), and eggshell paint (right).

3.4. Conclusion

This chapter has presented novel results, providing a greater understanding of paint topography. The outcome from the microscopy studies have been essential in explaining most of the results presented in Chapter 2. A significant difference in the morphology and topography of matt and non-matt paints, was evident when examining the SEM images at 25,000x magnification. It is apparent that matt paint dries with a porous finish, due to the large number of particles that extend well above the binder layer, in addition to a wide range in size and shape of the particles. It is also noticeable that silk, bathroom and Duracoat paints dry with a semi-porous finish, with small uniform particles that are well adhered to the binder layer, but protrude slightly above.

On the other hand, it is obvious when examining the SEM images that eggshell and gloss paints dry with a non-porous finish, with small uniform particles, which are located well within the binder layer. These findings have an understandable effect on the recovery of fingermarks and it is vital that the correct set of processes are used on each paint type, depending on whether it dries as a porous, semi-porous, or non-porous surface.

The development of the 'wipe test' will aid practitioners in determining the type of paint that has been applied to the walls of a crime scene, so that they are able to utilise the correct set of processes on the walls to maximise the yield of developed fingermarks. The findings from this chapter, in addition to those in Chapter 2, have informed the final experiments to ascertain which development processes are the most effective at developing latent fingermarks on painted walls '*in situ*' at crime scenes (Chapter 4).

Chapter 4 – Investigation of visualisation methods

4.1. Introduction

This chapter includes tests for alternative fingermark development processes on painted walls to ascertain whether or not these are more efficient at developing latent fingermarks, compared to the commonly used methods that were tested in Chapter 2 (sections 2.4.2.1. and 2.4.3.1.). As discussed in Chapter 1, researchers have investigated a variety of other processes that can be used on painted walls (Flynn, et al., 2004; Lawrie, 2007; Fletcher, 2009; Lawrence, et al., 2010; Bleay, et al., 2013; Bandey, et al., 2014), and therefore some of these complementary processes were explored further. The culmination of this chapter resulted in establishing the most efficient processes to use on different paint types. This information was then used in Chapter 5 to determine an efficient sequential work flow of fingermark development processes for different paint types, which can be disseminated to fingermark practitioners working in the field. This will fill the gap in knowledge surrounding the issue of developing fingermarks on painted walls, and will aid towards providing vital information to be used in fingermark recovery strategies.

This chapter is composed of three separate sets of experiments. The first of which aimed to ascertain the most appropriate time frame in which to record and assess latent fingermarks that have been processed using the amino acid reagents ninhydrin (previously tested on painted substrates) and indandione (newly tested on painted substrates), as discussed in section 2.4.4. It is recommended that substrates that have been treated with ninhydrin are placed into a humid oven at 80^{o}C temperature and 62% humidity, and those treated with indandione should be placed in a dry oven at 100^{o}C (Bandey, et al., 2014; Bleay, et al., 2017; Sears, 2017). However, some surfaces, such as painted walls, cannot be removed and processed in a controlled laboratory environment. Therefore, it is vital that the optimum time frame between processing and assessing fingermarks '*in situ*' at scenes is explored in detail in order to ensure that the best quality marks are obtained before they begin to fade.

The second set of experiments tested the suitability of alternative development processes (indandione, iodine, powder suspension and silver nitrate), which are not currently used on painted walls. These processes were chosen from the Fingermark Visualisation Manual (Bandey, et al., 2014), as they were deemed to be suitable for application '*in situ*' on painted walls. These results, along with those presented in Chapter 2 (sections 2.4.2.1. and 2.4.3.1.), will allow for the most efficient development methods to be identified for each paint type.

The third and final set of experiments in this chapter sought to determine which processes (identified from the testing of alternative processes) are the most effective at developing latent fingermarks on painted walls at crime scenes, using donors. In order to test this, a number of different paint types were examined (as per experiments in Chapter 2, section 2.4.2.1.) using a large number of donors (N=30) to provide a representative sample of the population (Sears, et al., 2012; International Fingerprint Research Group, 2014). The results of these experiments can be utilised by practitioners to decide which technique could be employed at volume crime scenes, and which techniques could be used sequentially at serious and major crime scenes to maximise the potential yield of fingermarks.

4.2. Materials and methods

4.2.1. Materials

Iron (II/III) oxide (CAS-1317-61-9), methanol (CAS-67-56-1) (HPLC Grade), ethylene glycol (CAS-107-21-1) (extra pure), glass beakers (various sizes) and disposable pipettes (3.2ml) were all purchased from Fisher Scientific, UK; Triton X-100 (CAS-9002-93-1), zinc chloride (CAS-7646-85-7), iodine (CAS-7553-56-2) were all purchased from Sigma Aldrich, Germany; Basic yellow 40 was purchased from Sirchie, USA; Cyanobloom, MVC3000 Cyanoacrylate Vapour Chamber, blue Crime Lite (wavelength range 420-470 nm), UV Crime Lite (wavelength range 350-380 nm), GG495AG viewing goggles and camera filter (1% transmission point - 476 nm), 530BP viewing goggles and camera filter

(1% transmission point - 495 nm), 550BP viewing goggles and camera filter (1% transmission point - 512 nm), GG420AG viewing glasses and camera filter (1% transmission point - 408nm) were all purchased from Foster and Freeman, UK. All other materials were purchased as described in Chapter 2 - section 2.3.1. and Chapter 3 – section 3.2.1.

4.2.2. Methods

4.2.2.1. Preparation and application of development processes

In total, 7 development processes were utilised; indandione, iodine solution, silver nitrate solution, powder suspension, black magnetic granular powder, ninhydrin and cyanoacrylate vapour. Each process was prepared and applied as follows:

4.2.2.1.1. Indandione

The indandione solution was prepared in accordance to the Home Office Fingermark Visualisation Manual update (Sears, 2017). 0.25 g of 1,2-indandione was mixed with 45 ml ethyl acetate, 45 ml methanol, 10 ml acetic acid, 1 ml zinc chloride stock solution (0.1 g zinc chloride, 4 ml ethyl acetate and 1 ml acetic acid) and 1 L of HFE7100. This solution was stored at room temperature ready for use.

The indandione solution was applied to the substrates using a soft squirrel hair brush until the whole area was coated. The boards were then left to develop naturally at room temperature. In order to visualise the fluorescent marks, they were excited with an 82S Crime Lite – blue/green (445-510 nm), and viewed using OG 550 AG orange filtered goggles (529 nm) (Sears, 2017). Images were captured using an OG 550 AG orange lens filter (529 nm) on the camera lens.

4.2.2.1.2. Iodine solution

The iodine solution was prepared in accordance to the Home Office Fingerprint Source Book (Bleay, et al., 2017). 0.4 g of iodine was combined with 194 ml heptane to produce the iodine solution, which was stored at room temperature ready for use. The iodine solution was applied in a similar manner as described in section 4.2.2.1.1. Any developed marks were immediately photographed and graded (within 5 mins) (explained in section 4.2.5 and Table 14) due to the likelihood of them rapidly fading (Bleay, et al., 2013).

4.2.2.1.3. Silver nitrate solution

The silver nitrate solution was prepared in accordance to the Home Office Fingermark Visualisation Manual (Bandey, et al., 2014). 10 g of silver nitrate was dissolved in 500 ml methanol to produce the silver nitrate solution, which was stored in the dark and at room temperature until used. The silver nitrate solution was applied in a similar manner as described in section 4.2.2.1.1. The surfaces were then illuminated by a blue Crime Lite (420-470 nm) for 2 minutes in order to accelerate the processing of the marks, before being photographed and graded in natural light (as discussed in section 4.2.5 and Table 14).

4.2.2.1.4. Powder suspension

The powder suspension was prepared fresh on each occasion in accordance to the Home Office Fingermark Visualisation Manual (Bandey, et al., 2014). 250 ml of Triton-X 100 was combined with 350 ml of ethylene glycol and 400 ml of deionised water to produce a stock solution). The powder suspension was then obtained by combining 50 ml of the stock solution with 50 g of iron oxide, which was mixed using a soft squirrel hair brush, and applied in a similar manner as described in section 4.2.2.1.1. This was then left on the substrate for 15 seconds before being gently rinsed off using tap water, which was applied using a squeezy bottle. The boards were then left to dry for an hour before being photographed and graded in natural light, as discussed in section 4.2.5 and Table 14.

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4.2.2.1.5. Black Magnetic Granular Powder

The black magnetic granular powder was applied to the substrates with a magnetic wand using a methodical sweeping motion to ensure that all of the surface area had been in contact with the powder. Once developed the boards were then photographed and graded on the same day as discussed in section 4.2.5 and Table 14.

4.2.2.1.6. Ninhydrin

The ninhydrin solution was prepared and applied as described in section 2.3.2.1.1. The boards were then left to develop naturally at room temperature before being photographed and graded on day 1, 2 and 3 post-treatment as discussed in section 4.2.5 and Table 14.

4.2.2.1.7. Cyanoacrylate Vapour

The cyanoacrylate vapour chamber (Foster and Freeman MVC3000) was programmed so that all variables were kept constant throughout processing (Relative humidity – 80%; Glue temperature - 120ºC; Glue time – 15 mins). 3 g of Cyanobloom was placed into the foil dish and placed onto the hot plate. The boards were placed vertically onto the wire shelf in the centre of the chamber. After development the boards were photographed using reflected UV Crime Lite (350-380 nm) and the subsequent images were then graded. The boards were then further processed using Basic Yellow 40 before being photographed and graded as discussed in section 4.2.5 and Table 14.

4.2.2.1.8. Basic Yellow 40

The Basic Yellow 40 solution was prepared in accordance to the Home Office Fingermark Visualisation Manual (Bandey, et al., 2014). 1 g of Basic Yellow 40 dye was combined with 2 ml powder suspension stock solution (discussed in section 4.2.2.1.4.), and 1 L water (to produce the Basic Yellow 40 aqueous solution). The solution was applied to the boards in a similar manner, as described in section 4.2.2.1.1. The surfaces were then rinsed using tap water, which was applied using a squeezy bottle, and then left to dry.

Once dry, the boards were visualised using a Blue Crime Lite (420-470 nm), which was then imaged using GG495AG filter (476 nm), 530BP filter (495 nm), 550BP filter (512 nm), and a UV Crime Lite (350-380 nm), which was then imaged using GG420AG filter (408 nm). The marks were then graded as discussed in section 4.2.5 and

Table 14.

4.2.2.2. Time optimisation of ninhydrin and indandione

Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (200 x 150 mm) to provide simulated walls (N=16). Each board had one of four paint types (matt, silk, bathroom or eggshell) applied to it. Paints were applied using a medium pile mini roller to provide an even layer of paint to the boards, as discussed in section 2.3.4. After 1 week, the board was divided into 30 sections (6 x 5) and then 6 donors each deposited 5 single fingermarks (not a depletion series) onto an allocated section of the board. Subsequently, 24 hours after deposition, either ninhydrin or indandione was applied to the boards. The boards were visualised and imaged during a range of time frames; 0.5 days (4 hours), and then once a day from 1 day to 8 days. In total, 2,160 fingermarks were graded in this experiment; 1,080 of which were graded from each process and 540 were assessed on each of the 4 paint types

4.2.2.3. Determining the effectiveness of alternative visualisation processes (indandione, iodine, powder suspension and silver nitrate)

Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (200 x 150 mm) to provide simulated walls (N=80). Each board was prepared using the method stated in section 4.2.2.2. After 1 week, the board was divided into 30 sections (6 x 5) and then 6 donors deposited 3 fingermarks onto an allocated section of the board. The boards were developed using indandione, iodine, powder suspension or silver nitrate after a range of time frames; 0.5 days (4 hours), 1 day, 2 days, 4 days and 1 week. The total number of marks deposited for this experiment were 1,440 (18 fingermarks on 80 boards).

4.2.2.4. Comparison of the most effective development processes (black magnetic granular powder, powder suspension, ninhydrin, cyanoacrylate vapour)

Sheets of Knauf Plasterboard (1200 x 900 mm) were cut into smaller boards (200 x 300 mm) to provide simulated walls (N=144). Each board was prepared using the method stated in section 4.2.2.2. After 1 week, the boards were divided into 30 sections and 30 donors (of mixed gender, age and ethnicity) were recruited to donate one fingermark per board, using the same section on each board to allow for direct comparisons. Each participant started their depositions on different boards to obtain an even distribution of residue levels. The total number of marks deposited for this experiment was 4,320 (30 fingermarks on 144 boards). The boards were developed using black magnetic granular powder, powder suspension, ninhydrin or cyanoacrylate vapour either a day, a week and a month after deposition to imitate the realistic time frame in which a crime scene would be examined (Sears, et al., 2012).

4.2.3. Donation of fingermarks

Donors were given a set of instructions, as previously outlined in section 2.3.4. (Table 12), and started their depositions on different boards to gain an even distribution of residue levels.

4.2.4. Storage of plasterboard during experimentation

All boards were stored in general room conditions throughout the experiments to imitate the environmental conditions commonly found within indoor crime scenes, with fluctuations in natural light occurring through an adjacent window.

4.2.5. Visualisation and recording of developed marks

Boards were immediately photographed prior to grading using a Nikon D90 camera. All fingermarks developed during the experiments were individually viewed using a linen glass and the quality of fingermark ridge detail developed was graded using the adaptable Home Office scale of 0-4, as discussed in section 4.2.5 and presented in Table 14 (Bandey, 2004; Sears, et al., 2012; International Fingerprint Research Group, 2014).

4.2.6. Statistical analysis

All grades were stored electronically and assessed as described in section 2.3.2.7. All of the data gained in this chapter was also non-parametric.

4.3. Results and Discussion

4.3.1. Time optimisation of ninhydrin and indandione

The purpose of these experiments was to ascertain the most appropriate time frame in which to view, assess and image fingermarks that have been developed using the amino acid reagents ninhydrin and indandione. As discussed in Chapter 2 (section 2.4.4.), when using the grading system (Table 14), the quality of each ninhydrin developed mark deteriorated between 3 to 10 days, contrary to published literature (Kent, 2013b; Bandey, et al., 2014; Bleay, et al., 2017). This suggests that processed marks may take several days (or even weeks) to fully react. Therefore, both ninhydrin and indandione were tested, and the results (Table 25) showed that ninhydrin out performed indandione both in quality and quantity across all paint types studied. Both processes showed a positively skewed distribution over time (as discussed in Appendix 2) and therefore non-parametric statistical tests were applied.

Table 25 - Total number of fingermarks graded according to process (ninhydrin and indandione) (N=2160)

Development process (n=1080)	Number of fingermarks (grade 1 to 4)	Number of quality fingermarks (grade 3 or 4)
Ninhydrin	675 (63%)	105 (10%)
Indandione	207 (19%)	16 (1%)

As shown in Table 25, the total number of fingermarks developed (and graded 1 to 4) with ninhydrin was 675, compared to 207 with indandione. These results show a substantial difference of 468 fingermarks (44%). A similar difference was noted when assessing the number of quality fingermarks (graded 3 to 4), where ninhydrin out performed indandione (89 fingermarks, or 9%).

The results for the Mann-Whitney U test, returned a *p* value of <0.05 (at 95% confidence level) showing that the differences in the performance of both processes were significant when tested on the four main paint types together (matt, silk, bathroom and eggshell). This was then examined in closer detail, separating each paint type, however the Mann-Whitney U test, returned *p* values of <0.05 for all comparisons, revealing that the results did not differ according to paint type.

The results shown in Table 25 contradict many other publications, which state that indandione outperforms ninhydrin on a number of porous substrates (Levin-Elad, et al., 2017; Nicolasora, et al., 2018b). However, the majority of substrates tested in these studies were types of paper (including envelopes, cardboard and tickets), as these are routinely recovered from crime scenes (Daluz, 2015; Pires, 2017). Consequently, compared to paints, these items are more acidic and contain a high proportion of cellulose (Launer, 1939).

Therefore, variations in pH and cellulose levels will have an impact on the development of the indandione or ninhydrin, which will subsequently affect the development of latent marks (Spindler, et al., 2011; Bleay, et al., 2017; Nicolasora, et al., 2018b). In addition to this, fingermarks that are absorbed into cellulose materials remain relatively stable over time, and therefore marks can successfully be developed at a later date (Champod, et al., 2004; Hansen and Joullié, 2005; Daluz, 2015).

Conversely, paint does not contain cellulose, as discussed in Chapter 3 (section 3.3.2.3), and therefore the results obtained on painted substrates will differ considerably from those on paper. This explains why the use of indandione on painted substrates, even on matt paint (porous), was not as effective as it might be on paper. This also emphasises why both ninhydrin and indandione may be inefficient at developing fingermarks on painted walls.

4.3.1.1. Effect of ninhydrin and indandione over time

Despite the differences noted in the overall performance of ninhydrin and indandione, it is important to assess the quality of each processed fingermark on a daily basis. This will allow for the optimum time frame to be established in which a mark should be viewed and recorded by fingermark practitioners. Therefore, the time frames to be tested are divided into days rather than hours, as more time can be dedicated to serious and major crime scenes, compared to volume crime scenes; many of which are examined within the space of a single day (Monckton-Smith, et al, 2013). It is important to note that only FLOs are trained to apply both ninhydrin and indandione, and therefore these processes would only be used at serious and major crime scenes since FLOs do not routinely attend volume scenes, as discussed within the questionnaire (section 2.2.2.2.). The results from this study show that the optimum time differs according to development technique used, as shown in Figure 39.

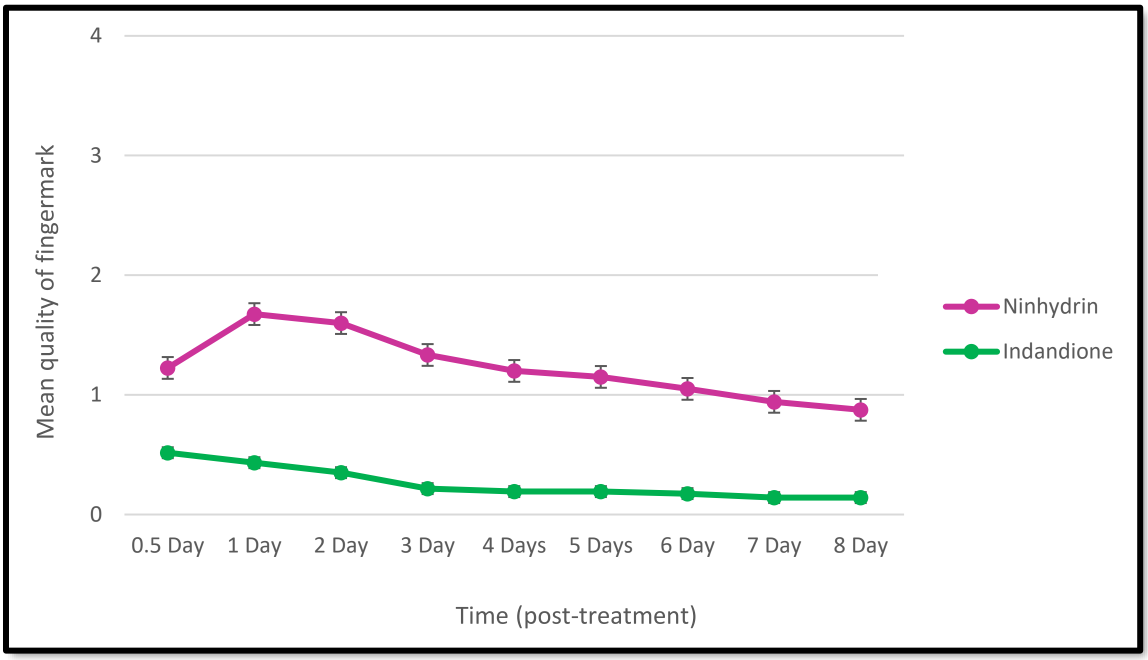

Figure 39 - Chart comparing effect of process (indandione and ninhydrin) over time (0.5 to 8 days post treatment) on all paint types (with standard deviation bars)

Figure 39 displays obvious differences in the results of ninhydrin and indandione. The optimum time to visualise marks developed with indandione is within 0.5 days post treatment, and then there is a decline in mark quality as time progresses. Conversely, the peak time to visualise marks processed with ninhydrin is 1 day post treatment, before the quality of fingermarks decline as time progresses. Over time the marks fade, reducing the levels of contrast between the fingermarks and the background (Figure 40), before fading completely.

Figure 40 - Images showing the fading of ninhydrin developed marks over time, from day 1 (left), to day 5 (right)

In order to ascertain if the results from both processes were significantly different, and would therefore warrant different guidelines to be produced for practitioners to follow, the Kruskal-Wallis test was applied. The results returned a *p* value of <0.05, (at a 95% confidence level) meaning that the results were statistically significantly different. Therefore, separate guidance should be produced for the optimal time in which to visualise ninhydrin and indandione.

The results presented in Figure 39 are contradictory to previous research (Roux, et al., 2000; Wiesner, et al., 2001). For example, this examination of ninhydrin and indandione showed that ninhydrin takes longer to react with the amino acid deposits to produce a mark of good contrast, whereas another study found that indandione reacts at a similar rate to ninhydrin (Wiesner, et al., 2001). This may be due to 1,2-indandione having a slightly different reactivity towards amino acids than ninhydrin (Luscombe and Sears, 2018). Other publications state that indandione can develop fingermarks at room temperature, but that the process may take 4-5 days to reach optimum contrast (Roux, et al., 2000). However, these results show that the optimum time to visualise marks that have been developed with indandione at room temperature is 0.5 days post treatment.

The differences found between this experiment and other published research could be due to environmental factors and substrate differences. Heat and humidity play a vital role in the reaction of indandione and ninhydrin (Ramotowski, 2013a). Therefore, the results of experimental work carried out in the UK should not be directly compared to work carried out in other countries with differing climates.

It is also suggested that different formulations of amino acid reagents, particularly indandione, should be used according to localised climatic conditions and the substrate concerned, as the results of each different formulation vary greatly (Yamashita and French, 2011; Nicolasora, et al., 2018b).

As indandione is a new process that has only recently been introduced into UK fingermark practice, at present there is limited research available to suggest how successfully it performs when left to develop naturally at room temperature within the UK climate. Therefore, it is unclear how reliable indandione is when used '*in situ*'.

Nevertheless, this study also obtained contradictory results to other UK research regarding ninhydrin. The results from these experiments show that the optimum time frame in which to visualise marks developed using ninhydrin is 1 day post treatment, after which the quality and quantity of fingermarks declines. These findings are supported by the results presented in section 2.4.4. and are in accordance with Daluz (2015). However, other researchers suggest that marks may require longer (up to two weeks) when developed naturally (Bandey, et al., 2014; Luscombe, 2016; Bleay, et al., 2017). The results of this study show that a large proportion of fingermarks could be missed, owing to the decline in fingermark quality over time.

On the other hand, it is recommended that it is important to image marks processed with amino acid reagents as soon as they are fully developed, as the marks will fade over time and thus the contrast will decrease (Bandey, et al., 2014; Bleay, et al., 2017). These findings are mirrored in this study, as the quality of the marks developed using both indandione and ninhydrin decreased as time progressed (after 0.5 days and 1 day respectively).

Conversely, other studies claim that marks developed with ninhydrin are stable and, if stored in the dark, they would remain almost indefinitely (Ramotowski, 2013a). It is not clear whether this would have been the case in this research, as the developed marks were kept under normal room conditions with natural light entering via a window, in order to simulate general conditions encountered at crime scenes. It would be difficult to keep crime scenes dark at all times and therefore it should be assumed that marks will not remain indefinitely, but will fade as time progresses, as shown in this study.

4.3.2. Effectiveness of alternative visualisation processes (indandione, iodine, powder suspension and silver nitrate)

To establish if any alternative processes might be effective at developing latent fingermarks on painted walls '*in situ*', indandione, iodine, powder suspension and silver nitrate were tested. Using published research (Bandey, et al., 2014; Bleay, et al., 2017), a range of alternative processes were reviewed to ascertain if they were suitable for use in crime scenes (presented in Table 4, Table 5, Table 6, and Table 7). The experimental work in this section concentrated on processes that were feasible for use on painted walls in crime scenes by either CSEs or FLOs, therefore the aforementioned processes were selected (the overall results of which are presented in Table 26). All other processes were considered impractical for static vertical surfaces (i.e. walls), painted substrates, or had health and safety issues when used outside of a controlled laboratory environment.

Table 26 - Total number of fingermarks graded according to process used (indandione, iodine, powder suspension and silver nitrate) on all paint types combined (N=1440)

Development process (n=360)	**Number of fingermarks (grade 1 to 4)**	**Number of quality fingermarks (grade 3 or 4)**
Indandione	78 (22%)	2 (0.5%)
Iodine	26 (7%)	0 (0%)
Powder Suspension	102 (28%)	12 (3%)
Silver Nitrate	124 (34%)	2 (0.5%)

In total, 1,440 fingermarks were deposited in this experiment, 360 marks of which were developed with each process. As shown in Table 26, the process that developed the highest number of marks on all paint types combined (grade 1 to 4) was silver nitrate, which developed 124 of a possible 360 marks, equating to 34%. Powder suspension was also successful in developing 102 marks (grade 1 to 4), which equates to 28% of available marks. However, indandione and iodine were not as effective in processing latent marks, as only 78 (22%) and 26 (7%) were developed respectively.

However, when assessing the number of quality marks (grade 3 or 4), it was powder suspension that was most effective, developing 12 (3%) of available marks, compared to silver nitrate, which only developed 2 marks (0.5%). This shows that whilst silver nitrate was efficient in developing marks, it was not able to produce detailed marks of good contrast, which would be necessary for identification purposes (Daluz, 2015).

In order to ascertain if the results in Table 26 were statistically significant the Kruskal-Wallis test was applied which returned a p value of <0.05, meaning that the results were significantly different. However, when analysing the data more closely, using the Mann-Whitney U test, it was revealed that the results for powder suspension and silver nitrate were not significantly different (p value of 0.19), and neither were the results for powder suspension and indandione (p value of 0.12). However, it is clear that iodine is much less effective on painted surfaces, compared to the other three processes. This result opposes the findings of other publications, which have noted more successful outcomes when using iodine. The heptane formulation of iodine solution, which was used in this study, was found to be more efficient at developing marks on painted walls, compared to ninhydrin (Fletcher, 2009). Another researcher also found success when using a different formulation (iodine-benzoflavone) on painted walls, stating that iodine-benzoflavone was effective in developing freshly deposited marks (<1 day) (Flynn, et al., 2004). This study shows that iodine alone is not an effective process to use on contemporary painted walls, and may need to be used in conjunction with benzoflavone to gain optimum results. Therefore, at present iodine solution is recommended for use on painted walls when marks need to be developed quickly, due to significant time constraints (Bleay, et al., 2017). However, the use of iodine solution at crime scenes is problematic, as most formulations are flammable (Home Office Scientific Development Branch, 2007; Kent, 2013b; Ramotowski, 2013c). In addition to this, the developed marks are not stable and will disappear within a short time frame, and therefore must be assessed and imaged immediately by FLOs upon development (Jasuja, Kaur and Kumar, 2012; Kent, 2013b).

It is possible to use fixing methods in order to prolong the visibility of the developed marks. Such fixing methods include 7,8-benzoflavone and α-naphthoflavone (Jasuja, Kaur and Kumar, 2012; Bandey, et al., 2014). However, these are usually dissolved in harmful and/or flammable solvents which presents operational issues, and as such solutions should not be applied at scenes (Bleay, et al., 2017). Therefore, it is clear that iodine (alone) should no longer be recommended as a method to develop latent marks on painted walls in crime scenes (although it may be more successful when used with benzoflavone). Such processes require in depth health and safety risk assessments, and are less effective at developing marks compared to other processes according to the research presented in this study.

4.3.2.1. Effect of paint type on the efficacy of development processes

It is also important to note that the porosity of the painted surface will also have an effect on the development of latent marks. Whilst iodine performed poorly overall, it was slightly more successful on matt paint, which is a porous substrate and therefore better suited to porous processes, such as iodine, indandione and silver nitrate. Consequently, it is important to ascertain what effect the paint type has on the effectiveness of the development processes. Despite the differences noted in the overall performance of iodine, indandione, powder suspension and silver nitrate (Table 26), it is important to ascertain whether or not these results are generic to all paints, or whether the results differ according to the porosity of the paint. The results have therefore been examined much more closely and divided into paint types, as shown in Table 27 and Figure 41.

Table 27 - Total number of marks developed (grades 1-4) according to paint type (matt, silk, bathroom and eggshell) and development process (indandione, iodine, powder suspension and silver nitrate)

Paint type	**Development process**				**Total**
	Indandione	**Iodine**	**Powder Suspension**	**Silver Nitrate**	
Matt	19	15	0	30	64
Silk	32	3	30	34	99
Bathroom	27	7	30	31	95
Eggshell	0	1	42	29	72
Total	78	26	102	124	330

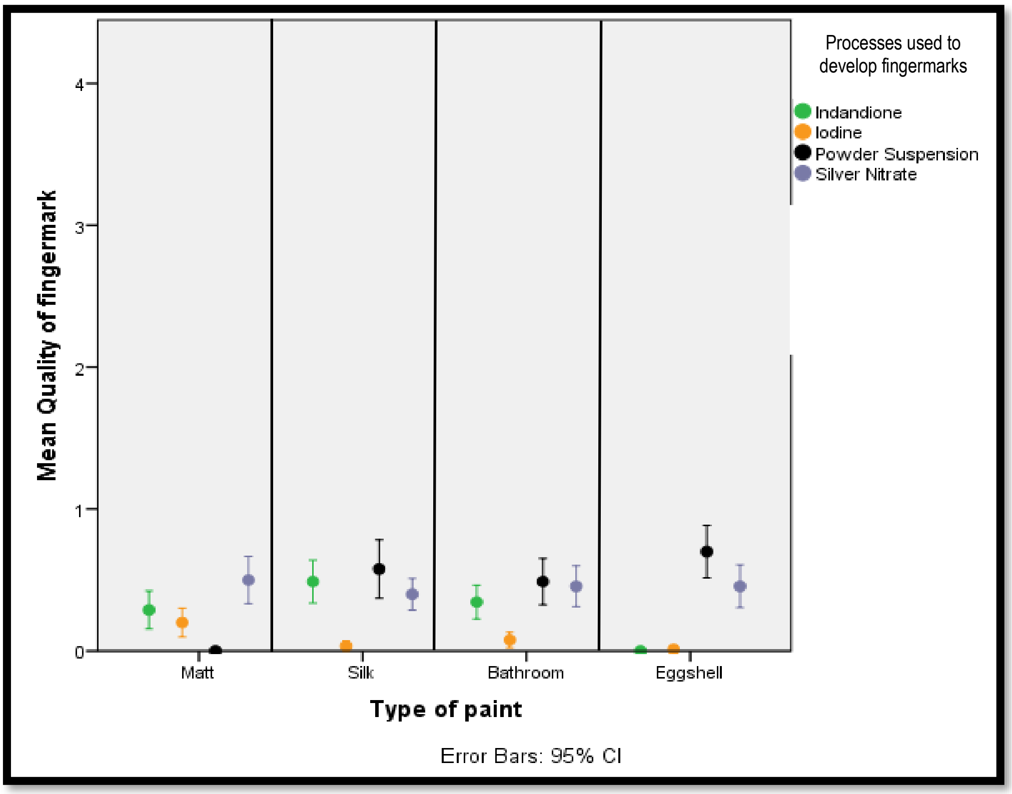

Figure 41 - Chart comparing effect of paint type (matt, silk, bathroom and eggshell) and development process (indandione, iodine, powder suspension and silver nitrate) used

As Figure 41 illustrates, all of the results (N=1440) achieved a mean mark of <1, showing poor quality fingermarks. However, there are differences in the spread of results according to paint type, as displayed in Table 27. For matt paint, the most effective process used was silver nitrate (30 fingermarks developed), whereas for all other paint types, the most successful technique used was powder suspension (silk and bathroom paint both developed 30 marks, and eggshell developed 42 marks). In order to determine whether or not the differences in results for each paint type were significant, the Kruskal-Wallis test was applied. The test returned a *p* value of <0.05, for each paint type, showing that the results were statistically significantly different at a 95% confidence level.

It is unsurprising that powder suspension was the most efficient process on silk, bathroom and eggshell paint, as these paints are semi/non-porous. As powder suspension is a semi/non-porous technique then it should achieve better results than the other 3 processes, which are most suitable for porous/semi-porous substrates (Lennard, 2001; Bandey, et al., 2014). These findings are in agreement with the results of other researchers who also note the potential of powder suspension for use on painted walls (Mehmet, 2010; Lawrence, et al., 2010; Sears, 2013). It has been stated that powder suspension is potentially much more effective at developing latent marks on walls, compared to iodine and ninhydrin (Bleay, et al., 2017); which is in line with the results found in this study (presented in section 4.3.2. - Table 26). In addition to this, some practitioners are already utilising this technique '*in situ*', as disclosed in the practitioner survey (Figure 10). It is important to note, however, that CSEs do not routinely have access to powder suspension and therefore it would be FLOs who apply this process '*in situ*', thus limiting its use to serious and major crime scenes.

Nevertheless, powder suspension was not effective on matt paint, which is a porous substrate; the reason for which is three-fold. Firstly, it is understood that fingermarks deposited on porous surfaces are absorbed into the substrate, rather than remaining on the surface (Champod, et al., 2004; Yamashita and French, 2011).

Therefore, when powder suspension is applied to the surface, it cannot interact with fingermark secretions, as most of the fingermark components will already have migrated into the substrate itself (Daluz, 2015). Secondly, the surface of matt paint is very textured, as shown in (section 3.3.2.5. - Figure 29), and therefore not all of the finger will make contact with the surface in order to leave a full mark. Therefore, it will be difficult to obtain a detailed fingermark with powder suspension, as the intermittent deposits will not form full ridge details (Henson and Jergovich, 2001; Bandey, et al., 2014). Finally, due to the highly textured topography of matt paint, there is a significant amount of background staining found when using powder suspension, as shown in Figure 42.

Figure 42 - Image showing background staining on matt painted board after powder suspension application

However, it is not just the application of powder suspension to matt paint that is problematic. There are also other, more general issues when using powder suspension '*in situ*' at scenes, as the process is very messy and can cause staining to neighbouring items (Bleay, et al., 2017). In addition to this, the excess water produced when rinsing the powder suspension from the walls should be fully considered prior to application, as this can be excessive and therefore the Environment Agency may need to be consulted (*ibid*).

Nevertheless, it is clear that powder suspension should be explored further to ascertain its viability as part of a sequential process for semi/non-porous paints. On the other hand, powder suspension should not be recommended for use on porous paints, such as matt. Instead, other techniques should be utilised, such as silver nitrate or ninhydrin, rather than iodine and indandione, which have been shown to be less efficient.

The results for silver nitrate were unexpected, as it is no longer commonly used in practice, due to it being less effective than other processes (Bandey, et al., 2014; Bleay, et al. 2017). However, this study has shown that for porous, matt painted surfaces, it may be beneficial to use as part of sequential process. It has been noted that silver nitrate could be used '*in situ*' and may be particularly useful when treating large areas (Bleay, et al., 2017). However, it is important to note that there are operational issues with using silver nitrate in large areas. Firstly, the methanol-based solution (which is recommended by CAST) is toxic and therefore should not be used at scenes (Schwarz and Hermanowski, 2011). Despite the health and safety issues, this method was initially tested in this study to ascertain if the most effective formulation would be effective, before trying less effective (water-based) formulations. Secondly, it is also difficult to control the rate of development, even when using high intensity light sources, and therefore the background colouration can become too dark, thus providing little contrast between it and the fingermark (Ramotowski, 2013b; Daluz, 2015). Thirdly, this process would be applied by FLOs rather than CSEs, thus limiting its use to serious and major crime scenes. It would also have to be validated for use on painted substrates as per ISO 17020 and 17025 accreditation regulations.

4.3.2.2. Effect of donor on the efficacy of fingermark development processes

When examining the paint types in isolation, it is clear that some processes are more efficient than others. However, it is not clear whether or not these processes are efficient on all latent fingermarks, or whether the results are donor specific.

Therefore, it is important to explore the effect of donor variation on the development techniques used. To investigate this, 6 donors were used (2 good donors, 2 fair donors, and 2 poor donors – assessed via large donor study in section 2.4.2.). In order to assess the effectiveness of the processes tested it is important to ascertain whether or not each technique reacts differently to each donor, and whether or not it would be effective on marks deposited by a large proportion of society as a whole. Therefore, the results for each of the 6 donors were examined in closer detail and are presented in Figure 43.

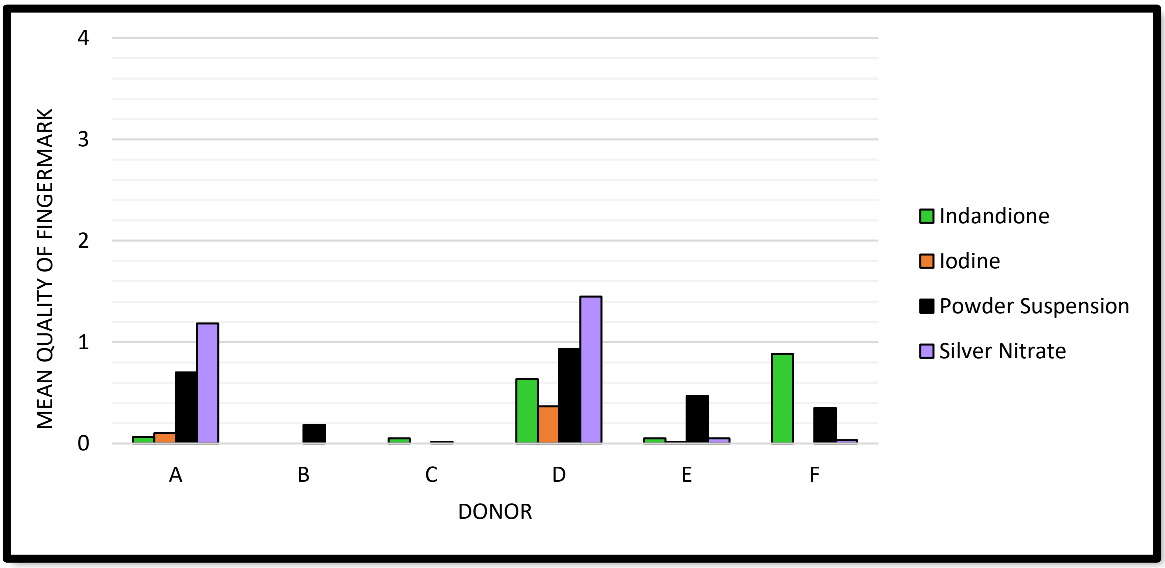

Figure 43 - Chart comparing effect of donor (A and D = good, E and F = fair, B and C = poor) on development process (indandione, iodine, powder suspension and silver nitrate) used on all paint types combined

As Figure 43 shows, there are obvious differences in both the quality and quantity of fingermarks developed according to donor. The two participants that were known to be good donors (from the results of previous studies) were A and D for both eccrine and sebaceous secretions. Both obtained results for all processes tested, with silver nitrate producing the best results, followed by powder suspension. Participants E and F were known to be fair donors (from the results of previous studies), both providing a number of results for powder suspension, and donor F also obtaining results with indandione, unlike donor E. Participants B and C were known to be poor donors (from the results of previous studies), showing a few results for powder suspension, with donor C also achieving a few results for indandione, unlike donor B.

Silver nitrate produced good results for 2 donors, however the other 4 donors did not have any marks that were developed using this process. It is important to note, that the quality of all fingermarks obtained during this experiment were generally poor (average grade <2 – not identifiable). Figure 43 also shows that silver nitrate is not a suitable method to use as a single process and should be used sequentially to ensure that marks from all types of donor are able to be visualised. On the contrary, powder suspension was the only technique used that developed marks deposited by all 6 donors. The Kruskal-Wallis test was applied to these results and a p value of <0.05 was returned too, showing that whilst all donors had marks developed with powder suspension, the quantity/quality of these marks varied significantly between donors at a 95% confidence level.

The inter-variability of donors is well researched, and a number of contributory factors are known to effect fingermark deposition (Croxton, et al., 2010; Stubbs, et al., 2015). In addition to the variations in fingermark composition, there are also differences in the physical deposition of marks between donors, which should also be considered (Fieldhouse, 2011b). It is therefore vital that additional research is undertaken with a larger pool of donors to ascertain whether or not the results shown in Figure 43 are universal, or specific to the 6 donors used in this study.

4.3.3. Comparison of the most effective development processes (black magnetic granular powder, powder suspension, ninhydrin, cyanoacrylate vapour)

To determine which of the development processes being tested were the most efficient at developing latent fingermarks according to paint type and age of mark, black magnetic granular powder, powder suspension, ninhydrin and cyanoacrylate vapour were used. For this set of experiments, the processes chosen were determined by their effectiveness (as discussed in sections 2.4.2.1, 4.3.2.1. and in published literature).

Black magnetic granular powder, which is a semi/non-porous process, was chosen as it is used by practitioners on painted walls (as discussed in Chapter 2 – section 2.2.2.2.) and it proved to be the most successful process in previous experiments (as discussed in Chapter 2 - sections 2.4.2.1. and 2.4.3.1.). In addition to this, black magnetic granular powder is the only one of the four processes chosen that can be applied by CSEs at crime scenes; meaning that it can be utilised at volume crime scenes, as well as serious and major scenes. The remaining three processes can only be applied by FLOs, which limits their use to the latter types of crime scenes.

Powder suspension, which is also a semi/non-porous process, was chosen as it was the most effective alternative process (for producing high quality marks), as discussed in section 4.3.2.1. Cyanoacrylate vapour, which is a semi/non-porous process, was also chosen to be tested. This process was not used previously in this study, primarily due to health and safety concerns, in addition to potential contrast issues between white polymer marks and light coloured painted walls (Lewis, et al., 2001; Khuu, et al., 2016). Nevertheless, cyanoacrylate vapour can be adapted for use '*in situ*', and there is a plethora of published research recognising it as an effective method on commonly found substrates, such as plastic (Bandey, and Kent, 2003; Fieldhouse, 2011a; Bandey, et al., 2014; Bleay, et al., 2017). Therefore, it was important to test this process, alongside others, to determine its effectiveness on painted walls.

Finally, ninhydrin, which is a porous/semi-porous process, was also included in the test, as it is commonly used '*in situ*' by practitioners (as discussed in Chapter 2 – section 2.2.2.2.). This was the most efficient 'porous' process identified, as it was more effective on a range of donors compared to indandione, silver nitrate and iodine solution (as discussed in Chapter 2 – sections 2.4.2.1 and 2.4.3.1, and Chapter 4 – section 4.3.2.1.) The overall results for these 4 processes are presented in Table 28, using data from all 4 paint types combined. It is clear that methods for semi/non-porous substrates are more effective than those designed for porous surfaces.

Table 28 - Total number of fingermarks graded according to process (black magnetic granular powder, ninhydrin, powder suspension and cyanoacrylate vapour) (N=4,320)

Development process (n=1080)	**Number of fingermarks (grade 1 to 4)**	**Number of quality fingermarks (grade 3 or 4)**
Black Magnetic Powder	728 (67%)	267 (25%)
Powder Suspension	538 (50%)	134 (12%)
Ninhydrin	382 (35%)	23 (2%)
Cyanoacrylate Vapour	737 (68%)	97 (9%)

In total, 4,320 fingermarks were deposited in this experiment; 1,080 of which were developed with each process. As shown in Table 28, the process that developed the highest number of marks on all paint types (grade 1 to 4) was cyanoacrylate vapour, developing 737 out of a possible 1080 fingermarks (68%). This was followed very closely by black magnetic granular powder, which developed 728 marks (67%). On the other hand, powder suspension and ninhydrin were shown to be less effective, developing 538 (50%) and 382 (35%) of all available fingermarks respectively. However, when evaluating the number of quality marks (grade 3 or 4), it was black magnetic granular powder that was most effective, developing 267 quality marks (25%), whereas cyanoacrylate vapour only developed 97 quality marks (9%). This shows that whilst cyanoacrylate vapour was generally efficient in developing marks, it was not able to produce marks with clear ridge detail, which would be necessary for identification purposes in casework.

In order to ascertain if the results in Table 28 were statistically significant the Kruskal-Wallis test was applied which returned a p value of <0.05, meaning that the overall results regarding development processes were significantly different from each other. These findings are complementary to the current practitioner guidelines for silk painted walls (which recommend the use of black magnetic granular powders, followed by either cyanoacrylate vapour or powder suspension).

However, these results contradict guidelines for matt painted walls (which recommend the use of DFO and ninhydrin, or powder suspension) (Bandey, et al., 2014). Therefore, it is important to explore these findings in more detail to ascertain whether or not they are applicable to all paint types, or are paint specific.

4.3.3.1. Effect of paint type on the effectiveness of development process

The overall results for these experiments were therefore divided according to paint type to determine which development process was the most effective for each paint. Table 29 and Figure 44 shows the results for each development process in conjunction with paint type.

Table 29 - Total number of marks developed (grades 1-4) according to paint type (matt, silk, bathroom and eggshell) and development process (black magnetic granular powder, ninhydrin, powder suspension and cyanoacrylate vapour)

Paint type	**Development process**				**Total**
	Black Magnetic Powder	**Ninhydrin**	**Powder Suspension**	**Cyanoacrylate Vapour**	
Matt	42	99	47	163	351
Silk	256	150	22	222	650
Bathroom	210	95	206	222	733
Eggshell	220	38	263	130	651
Total	728	382	538	737	2385

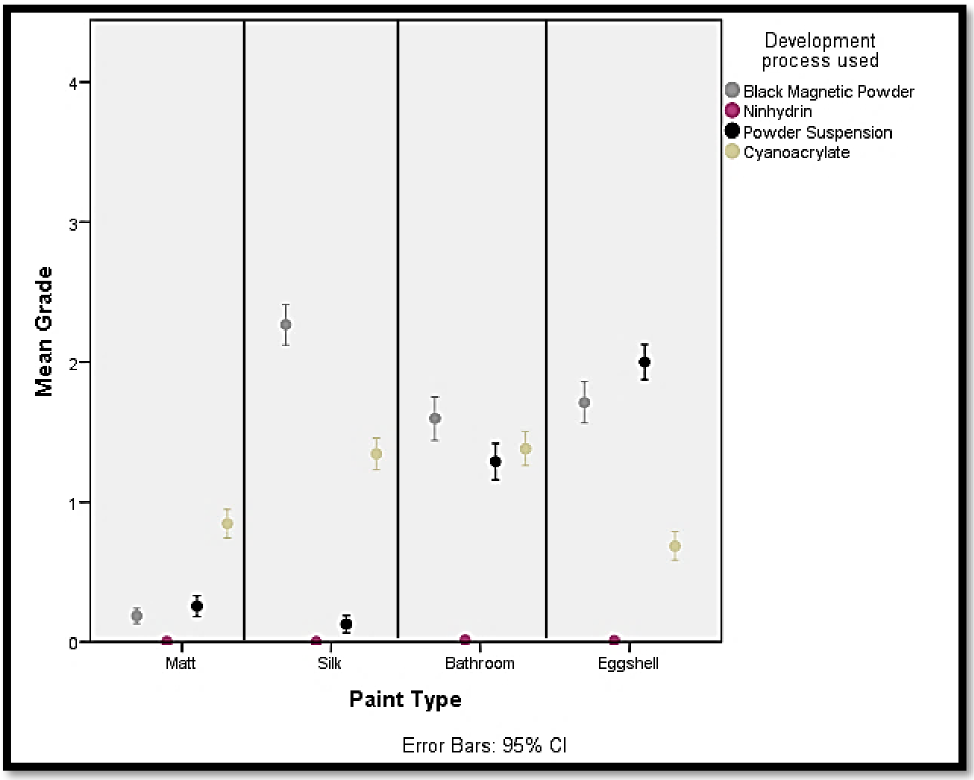

Figure 44 - Chart comparing effect of paint type (matt, silk, bathroom and eggshell) on development process (black magnetic granular powder, ninhydrin, powder suspension and cyanoacrylate vapour) used

As Table 29 and Figure 44 show, there are differences in the spread of results according to paint type. For matt paint, the most effective process used was cyanoacrylate vapour (163 marks developed), although the average grade obtained was 0.84. For eggshell paint, the most effective process was powder suspension with 263 fingermarks developed and an average grade 2.00. On the other hand, for both silk and bathroom paint, the most successful process in terms of mean marks was black magnetic granular powder (2.27 and 1.60 respectively). Conversely, bathroom paint developed a larger quantity of fingermarks with cyanoacrylate vapour (222 marks), compared with black magnetic granular powder (210 marks). However, the quality of marks developed with cyanoacrylate vapour (mean mark of 1.38) were not as clear as those developed with black magnetic granular powder (1.60).

In order to determine whether or not the differences in results for the 4 processes used on each paint type were significant, the Kruskal-Wallis test was applied. The tests returned *p* values of <0.05 for all 4 paints, showing that the results for the range of processes used on each paint type were statistically significantly different. The Kruskal-Wallis test was also applied to each development process to ascertain the effectiveness against the 4 different paint types. The results for black magnetic granular powder, cyanoacrylate vapour and powder suspension all returned a *p* value of <0.05, showing that the results for each process were significantly different across different paint types. However, the test for ninhydrin returned a *p* value of 0.26, showing that these results were not significant, thus meaning that the results for ninhydrin were similarly poor regardless of paint type.

It is clear from the results of the Kruskal-Wallis test, and Figure 44, that ninhydrin is not a valuable process when used on any type of painted walls, as the results are consistently low. This mirrors the results from Lawrence, et al., (2010), but contradicts current guidelines for matt paint, which recommends the use of ninhydrin, as part of a sequential process (Bandey, et al., 2014). Previous literature suggests reasons why ninhydrin may not be successful. For example, once the solvent in the solution has evaporated, the reaction between the amino acids and ninhydrin stops occurring (Ramminger, et al., 2001). In addition to this, substrates that are impervious to penetration do not allow the ninhydrin solution adequate time to be absorbed into the surface prior to the solvent evaporating, thus the reaction cannot fully take place (Shulenberger, 2015). One suggestion would be to alter the formulation of ninhydrin to include a slower evaporating solvent, allowing time for ninhydrin to react with the amino acids.

As discussed in Chapter 3 – section 3.3.2.3, silk, bathroom and eggshell paints are semi/non-porous, and therefore it would be difficult for the ninhydrin solution to be absorbed into the surface in sufficient time. One recommendation is to treat the area several times with ninhydrin, using a blank solvent wash between treatments, in order to increase the opportunity for the reaction to take place (Ramotowski, 2013a). However, this theory would not explain the poor results on matt paint which was shown to be porous.

It was suggested that the poor results for ninhydrin (and other processes) on matt paint may be attributable to the textured topography of the dried paint film, preventing full initial fingermark deposition (Henson and Jergovich, 2001; Bandey, et al., 2014; Daluz, 2015). However, this would not explain the effectiveness of cyanoacrylate vapour on matt paint. Research indicates that cyanoacrylate vapour may be more successful at developing latent marks on textured surfaces, as other techniques (particularly physical processes such as powders) may fill the voids of the surface, rather than adhering to the fingermark deposits (Bleay, et al., 2017). Cyanoacrylate, on the other hand, polymerises continuously during the fuming time, allowing for a more controlled development of the marks, which may explain the increased number of results on matt paint (Daluz, 2015).

Nevertheless, the use of cyanoacrylate vapour on light coloured painted surfaces, whether porous or non-porous, can be problematic, as found in this study. The polymer produced along the ridge details of any latent fingermarks is white, thus contrast is a significant issue if the substrate is also light coloured (Lewis, et al., 2001; Khuu, et al., 2016). Therefore, in order to increase the contrast between the mark and the background paint a dye may be used to colour the polymer, which will then fluoresce (Lennard, 2001).

In this study Basic Yellow 40 (BY40) was used in a water-based solution (rather than ethanol-based solution) to dye the polymerised marks. It is accepted that ethanol-based BY40 is more effective at dyeing developed marks and therefore should be the primary choice, however the solution is highly flammable and therefore should only be used in a controlled laboratory environment (Charlton, 2009; Bandey, et al., 2014; Khuu, et al., 2016). Therefore, when dyeing polymerised marks '*in situ*' at scenes, it is necessary to use the water-based solution, hence the decision to utilise the method in this study.

Consequently, there are issues when dyeing fingermarks that have been previously developed with cyanoacrylate vapour. Firstly, it is a messy process, as not only does the solution have to be 'painted' onto the wall, it also needs to be rinsed with water to prevent excessive background staining (Bandey, et al., 2014). In addition to this, some substrates (primarily those with increased porosity) are susceptible to background staining, thus not producing the desired contrast with the polymerised mark (Ramotowski, 2013c). This was an issue for some of the paint types tested in this study (especially matt paint) where the background was visibly stained yellow. This affected the subsequent fluorescent lighting examination of the walls using the specialised lights as the contrast between the background and the fingermark was minimal on matt paint compared to other paint types, as shown in Figure 45.

The use of one-step processes, such as Lumicyano™ and Polycyano, were not investigated as part of this study, but may be beneficial in these circumstances, as this would negate the need for basic yellow 40. Alternatively, it may be possible to gain contrast between the mark and the background by using powders in lieu of basic yellow 40 (Bandey, et al, 2014).

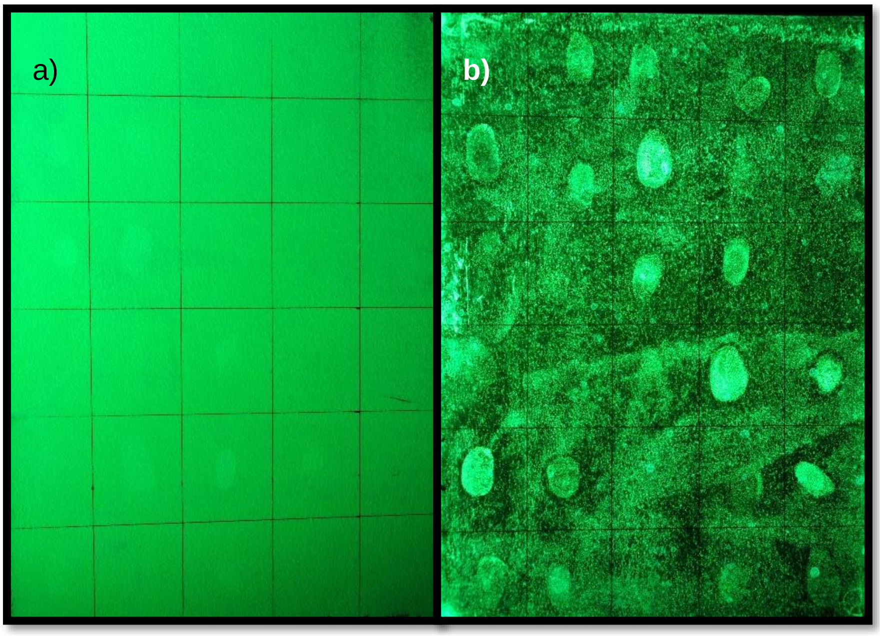

Figure 45 - Image showing background staining from BY40, illuminated with a Blue Crime Lite (420-470nm) and visualised with a GG495 filter on (a) matt painted board, compared with (b) bathroom painted board.

It is also important to note that whilst some good results were obtained using cyanoacrylate vapour on the painted boards, the method in which they were fumed is unrealistic. For this study, the boards were developed inside a controlled fuming cabinet, which is not feasible for painted walls '*in situ*' at scenes. Nevertheless, there is an alternative fuming method that has been developed for use at scenes called SUPERfume®. Whilst the results of this fuming system are not as effective as a traditional fuming chamber (due to the environmental conditions being less well controlled), it can still produce good quality marks on textured surfaces '*in situ*' (Bandey, and Kent, 2003; Fieldhouse, 2011a; Bleay, et al., 2017).

The two processes that produced the most results overall, are black magnetic granular powder and powder suspension; both of which can easily be applied to painted walls within a scene. Powder suspension produced good results for eggshell paint but was not as successful on other paint types. This may be due to the topography of the painted surfaces, as eggshell finishes as a smooth surface, whereas the other paint types had particles protruding above the binder layer (as discussed in Chapter 3 – section 3.3.2.3).

Previous research confirms this suggestion, stating that even subtle variations within the texture of the surface will affect the efficacy of powder suspension (Bacon, et al., 2013). Other factors that could affect the performance of this process relate to the particle size of the powder used and the quality of the chemicals used in the solution (Bleay, et al., 2017; Downham, at al., 2017). In addition to this, there are also issues in using powder suspension at scenes, due to it being a very messy process (as discussed previously in section 4.3.2.1.) (Bandey, et al., 2014; Bleay, et al., 2017).

Therefore, it is clear that black magnetic granular powder is the most effective method at developing latent fingermarks overall. These findings contradict some theories regarding the sensitivity of fingerprint powders, as they are deemed to be one of the least sensitive development techniques, requiring on average between 500 to 1000 ng of material to successfully develop a mark (Lennard, 2001). Ninhydrin, on the other hand, only requires around 100 to 200 ng to develop a similar size mark and therefore is thought to be more sensitive (*ibid*). However, many publications have stated similar findings to this study, noting the effectiveness of black magnetic granular powder, even on textured surfaces (Bandey, 2004; Bandey, et al., 2014; Bleay, et al., 2017). Powdering is still the predominant fingerprint development method in use, with around 50% of all identifications in the UK being from a powdered mark (Lennard, 2001; Bleay, et al., 2017). As it is a technique that can be applied by CSEs and FLOs alike, it can be utilised on painted walls at volume, serious and major crime scenes (Scenesafe, 2017). Therefore, black magnetic granular powder is not only the most effective process, but also the most practical process that can be used ‘*in situ*’. It is important to highlight the specificity of the powder type to practitioners (particularly CSEs), as the practitioner survey (discussed in Chapter 2 – section 2.2.2.2.) revealed that other powder types, such as aluminium flake and magneta flake, are being utilised on painted walls, despite being inappropriate to use on such substrates (Bandey, 2007). This highlights the need for further training of CSEs to ensure that they are using the correct development processes according to the surface that they are examining.

4.3.3.2. Effect of donor on the efficacy of development process

The overall results were divided according to donor to ascertain the impact of intra- and inter- donor variability on development processes. It is not clear whether the results obtained in this experiment are donor specific or are generalised across the population. Therefore, it is pertinent to explore these results in more detail to ascertain how each process performed according to donor. The results for this experiment were therefore divided per donor (N=30) to determine whether the effectiveness of each development process would vary across the population. Figure 46 shows the results for each development process alongside each participant who donated marks for this study.

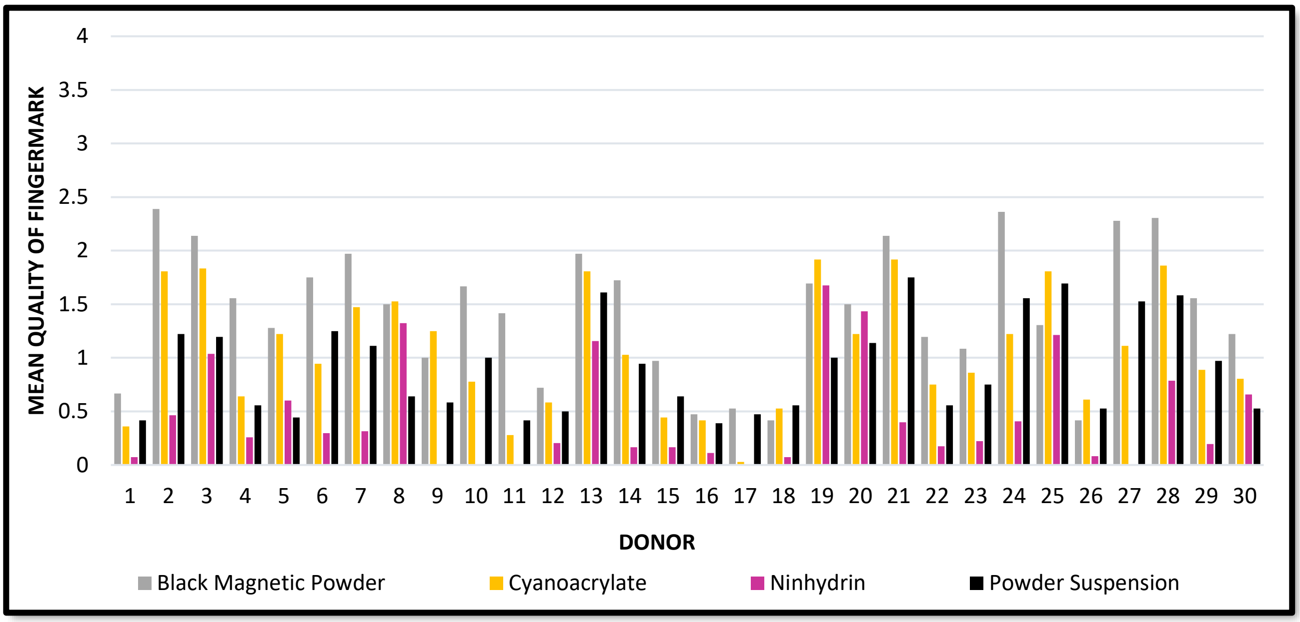

Figure 46 - Chart comparing effect of donor (N=30, 144 marks per donor) on development processes (black magnetic granular powder, cyanoacrylate vapour, ninhydrin and powder suspension) used on all paint types combined

As Figure 46 shows, of the 30 donors that took part in the study, 80% (n=24) had better results when black magnetic granular powder was used compared to the other 3 processes. When applying the Kruskal-Wallis test to the results for black magnetic granular powder, a p value of <0.05 was returned, showing that the differences between each donor were statistically significant.

Therefore, whilst this process was the most effective for 80% of donors (the mean marks of which are displayed in Figure 46), the actual results vary from being a very partial mark (grade 1) to a mark that is identifiable (grade 4). Figure 46 also shows that 17% of donors (n=5) had more fingermarks developed using cyanoacrylate vapour, and only 3% of donors (n=1) had more results using black powder suspension. The Kruskal-Wallis test was also applied to these results and a *p* value of <0.05 was returned for both cyanoacrylate vapour and black powder suspension, meaning that these results are also statistically different amongst donors.

Ninhydrin was the least efficient process of those tested in these experiments. Some participants, such as donor 19, had some good results with ninhydrin (although cyanoacrylate vapour was the most effective process for their fingermarks). Conversely, donors 9, 10, 11, 17 and 27 did not have any marks that were developed using ninhydrin. When applying the Kruskal-Wallis test to these results a *p* value of 0.62 was returned, showing that the results were not significantly different between donors.

As mentioned previously (section 2.4.5.), it is recognised that the inter- and intra-variability of donors' marks vary substantially (Frick, et al., 2013; Stubbs, et al., 2015). The findings of this study demonstrate that whilst the majority of donors showed an affinity to black magnetic granular powder, it is important to consider sequential processing in order to maximise the yield of fingermarks from crime scenes (Bandey, et al., 2014). This is particularly significant when dealing with major crime scenes, where additional techniques can be applied '*in situ*' by FLOs, compared to volume crime scenes where only CSEs would attend. In these cases, a fingermark recovery strategy would be developed in order to maximise the number of marks obtained. This process is not lengthy but does require time to formulate and implement, therefore it is vital to ascertain if the efficacy of the development techniques are affected by time.

4.3.3.3. Effect of time on the efficiency of development processes

The results were also arranged according to the age of the fingermarks in order to determine whether the effectiveness of each development process would vary in line with time. Figure 47 shows the results for each development process according to the age of the marks.

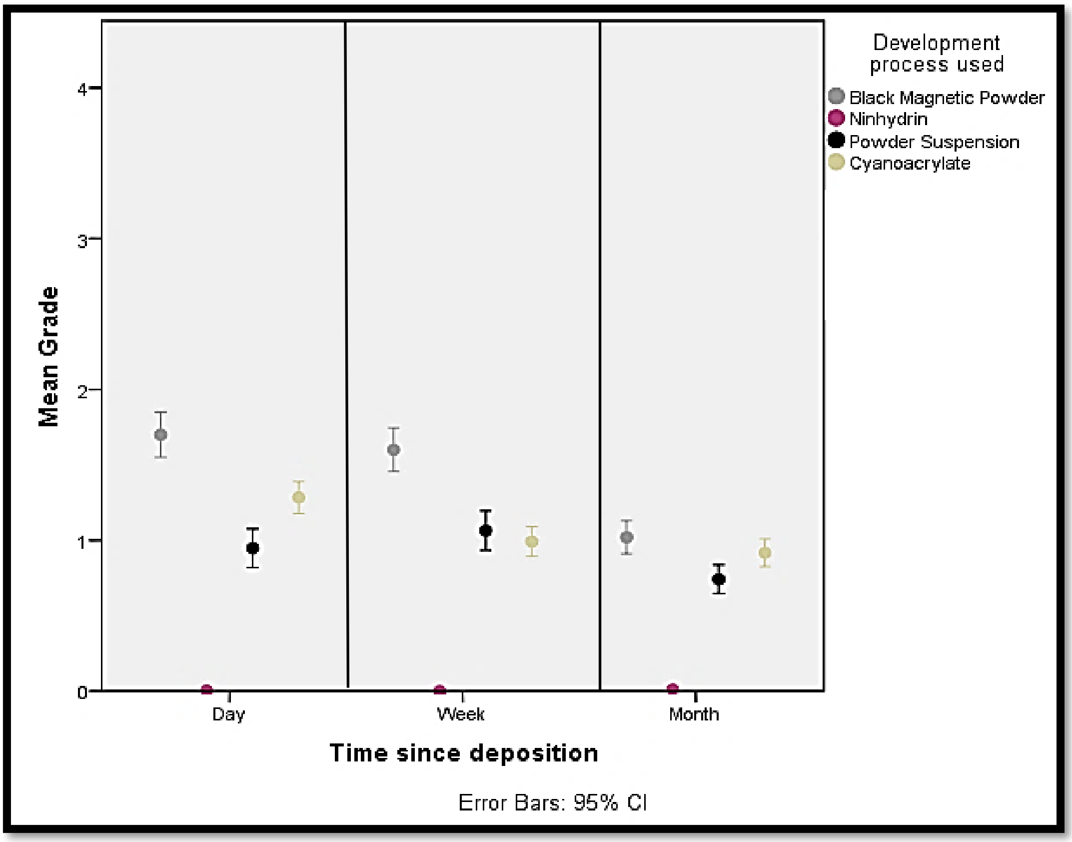

Figure 47 - Chart comparing effect of time on development process (black magnetic granular powder, ninhydrin, powder suspension, cyanoacrylate vapour) used on all paint types combined

As Figure 47 shows, some of the processes became less effective as time progressed. Black magnetic granular powder and cyanoacrylate vapour both gave better results on marks that were only aged for a day. The quality/quantity of marks then decreased (albeit at different rates) after a week, and then further decreased after a month. When assessing if the results from these processes were significantly different over time, the Kruskal-Wallis test was applied, giving a *p* value of <0.05, meaning that the results were statistically significantly different over time for each of the two processes.

Conversely, powder suspension and ninhydrin did not follow the same trend. Powder suspension gave better results on fingermarks that had been aged for a week, rather than a day. However, less marks were retrieved after a month, which was in line with the results gained from black magnetic granular powder and cyanoacrylate vapour. When the Kruskal-Wallis test was applied to these results, a *p* value of 0.05 was returned showing that statistically the results were significantly different over time to a 95% confidence level. Figure 47 also showed that the results from ninhydrin followed a different configuration to the other 3 processes. Over time, the results were relatively stable (very low mean mark <1) and did not differ significantly, as verified by the results obtained when the Kruskal-Wallis test was applied, and a *p* value of 0.17 was obtained.

The results for black magnetic granular powder and cyanoacrylate vapour follow the conventional trend, where the effectiveness of the process declines over time. This is primarily due to the changing chemical nature of the deposited latent mark, where there is microbial action and evaporation of various components (Frick, et al., 2013; Boudreault and Beaudoin, 2017). However, this rate of change varies greatly according to the environmental conditions of the crime scene, in addition to other factors, such as type of surface and donor variability (Lennard, 2001; Hawthorne, 2008). Nevertheless, it is widely accepted that the effectiveness of the processes used and the quality of fingermarks recovered will decrease with age (Yamashita and French, 2011; Ramotowski, 2013; Bandey, et al., 2014). Contrary to this theory, the effectiveness of powder suspension did not immediately decrease with time as expected. However, similar results have been obtained from other studies involving powder suspensions, where the quality of marks have increased within a short time frame due to the evaporation of some constituents, allowing easier interaction between eccrine deposits and the powder suspension solution (Dominick, et al., 2011; Bleay, et al., 2017). Nevertheless, the quality of marks processed with powder suspension did decrease between a week and a month in line with the other processes tested (Figure 47).

The results for ninhydrin have been consistently poor (when compared to non-porous processes) throughout this research. Published literature suggests reasons for this, as discussed previously in section 4.3.3.1. (Ramminger, et al., 2001; Shulenberger, 2015), and these findings are consistent with other studies examining the development of latent marks on painted walls (Lawrence, et al., 2010). However, the results from this study contradict current practitioner guidelines, which need to be amended to reflect the findings of this research and previous studies.

4.4. Conclusion

The aim of these studies was to ascertain which processes were the most efficient in developing latent fingermarks on painted walls '*in situ*' and how these results were affected over time. As discussed in Chapter 3, matt and non-matt paints are very different topographically, and therefore it was important to ascertain which processes are effective on each paint type.

After assessing porous processes (ninhydrin, indandione, iodine solution and silver nitrate) it is clear that these are not as effective as non-porous processes, such as black magnetic granular powder and powder suspension. Nevertheless, silver nitrate did produce some good results for a limited pool of donors (2 of the 6 donors) and therefore should be explored in more detail in future studies. When comparing ninhydrin with indandione, it became clear that despite promising results shown for indandione in other studies (which were primarily conducted on paper substrates) (Wiesner, et al., 2001; Lee and Joullié, 2015; Mangle, et al., 2015; Sears, 2017), it was not as effective as ninhydrin on painted substrates.

Whilst ninhydrin was more efficient than indandione, it was shown to be much less effective than non-porous processes and therefore fingermark recovery strategies should mainly focus on those and limit the use of porous processes. However, if ninhydrin was to be used '*in situ*' then marks should be visualised and recorded within the first few days post-treatment, as the results presented in Figure 39 showed that the effectiveness of such processes declines after 1 day – contrary to previous publications (Bandey, et al., 2014; Luscombe, 2016; Bleay, et al., 2017).

Non-porous processes were shown to be much more efficient at developing latent fingermarks on painted walls. Black magnetic granular powder was the most efficient process overall, however good results were also obtained when using powder suspension and cyanoacrylate vapour. As mentioned previously, it is vital that development techniques are not used in isolation, but as part of a sequential process in order to maximise the yield of fingermarks recovered from crime scenes. This is particularly important at major crime scenes, where practitioners are able to employ a number of appropriate techniques. However, at volume crime scenes, where practitioners are only equipped with powders, they will still be able to develop and recover latent fingermarks from a variety of painted walls if black magnetic granular powder is used. This information was used to inform Chapter 5, creating a new set of guidelines for practitioners, including methods enabling personnel to distinguish between paint types '*in situ*', in order that they can apply the correct sequential process to the painted wall.

Chapter 5 – Guidelines for practitioners

5.1. Introduction

This chapter aims to provide practitioners with a set of guidelines detailing the most suitable processes to use on each specific type of painted wall, and the most appropriate sequential order in which to do so. The results presented and discussed in Chapters 2, 3 and 4 were used to inform these guidelines, in addition to published literature. The guidelines will also highlight which process is the most effective technique overall for each specific paint (as well as sequential treatments). This will allow practitioners to identify and utilise the most efficient treatment when at volume crime scenes (where feasible), as sequential treatments are not normally used in these circumstances.

However, a key issue is that many practitioners are often unable to determine the type of paint that has been applied to walls within a crime scene, and therefore it would be difficult to follow any recommended guidelines. In order to counteract this issue, this chapter also introduces the 'wipe test' into the guidelines for practitioners. This methodology can be implemented '*in situ*' at scenes to establish what type of paint has been applied to a wall before applying the corresponding treatment processes in the correct sequential order.

Using the results presented in Chapters 2, 3 and 4, a set of guidelines have been constructed which should be utilised by practitioners to design fingermark recovery strategies. All of the recommended processes can be used '*in situ*' at scenes, with minimal health and safety concerns (Bandey, et al., 2014). However, the necessary 'clean up' of the processes should be considered in great detail prior to any treatment taking place, as this may constrain the type and number of processes that can be used.

5.2. Guidelines for matt paints

The current guidelines for practitioners were published by the Home Office Centre for Applied Science and Technology (CAST) in 2014, which primarily recommends the use of porous processes for matt painted walls, as displayed in Figure 48 (Bandey, et al., 2014). These guidelines are based upon research which was predominantly carried out at CAST, with various publications used to inform their research (Flynn, et al., 2004; Lawrie, 2007; Fletcher, 2009; Lawrence, et al., 2010; Bleay, et al., 2013; Bleay, et al., 2017).

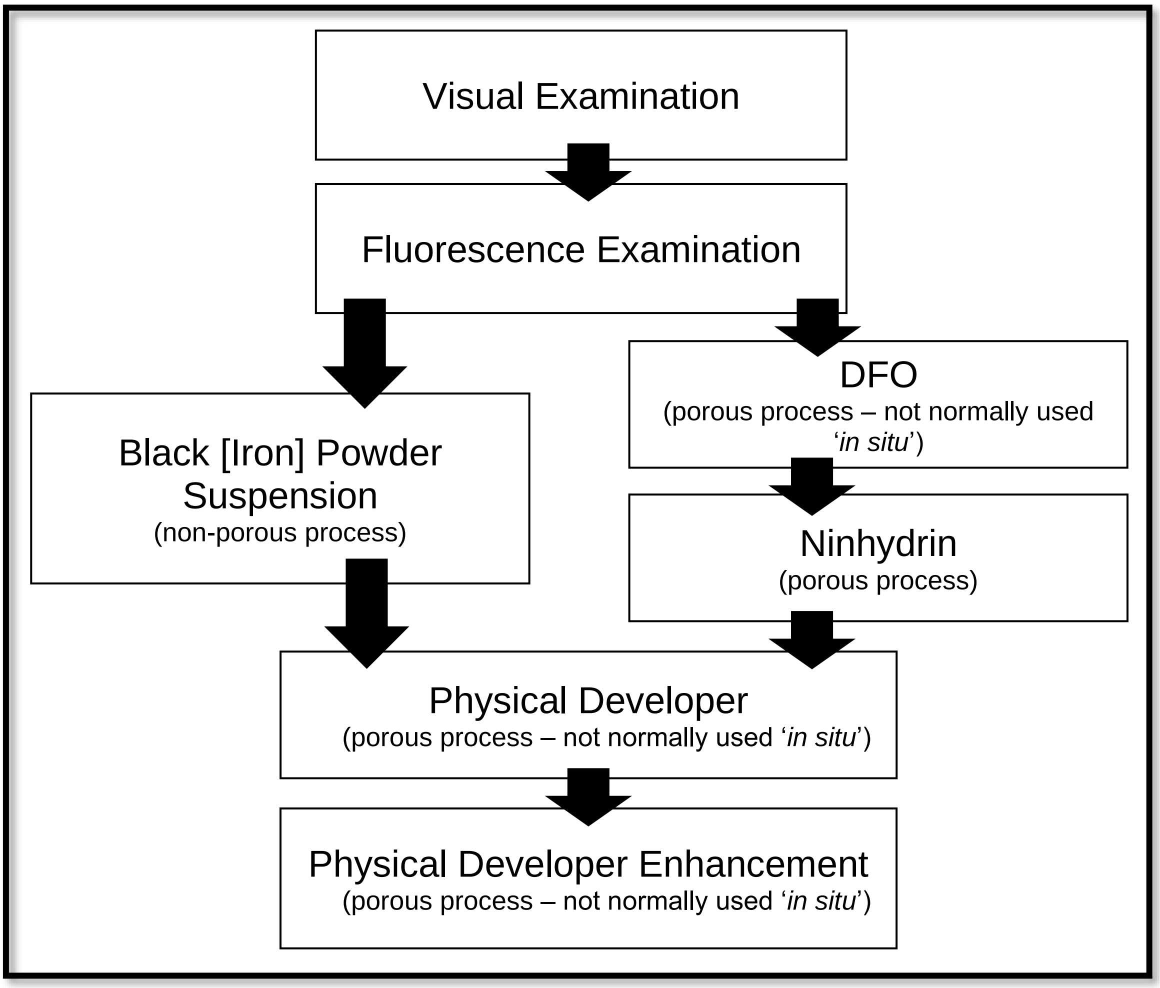

Figure 48 - Flowchart of the current recommended sequential processing of matt painted walls
(adapted from Bandey, et al., 2014).

However, this study has shown that porous processes are not effective at developing latent marks on matt painted walls. Ninhydrin, which is recommended by CAST (Figure 48) and is also commonly used by practitioners (Figure 10), was consistently outperformed by non-porous treatments, as discussed in section 4.3.3.1. On the other hand, it is important to note that both DFO and physical developer (plus enhancement) were not tested in this research. The reasoning behind the decision not to test these processes is that CAST states in the guidelines that "*DFO and Physical Developer are normally considered impractical due to the size (typically walls) and location (fixed at the scene) of the substrate*" (Bandey, et al., 2014).

In addition to this, recent publications have suggested that in future indandione will replace DFO as the starting point of sequential porous treatments, as it is much more efficient at developing marks on porous substrates (Luscombe, 2016; Levin-Elad, et al., 2017; Sears, 2017; Luscombe and Sears, 2018). Therefore, indandione was tested in this study instead of DFO.

Whilst the flowchart presented in Figure 48 primarily recommends porous processes, it also states that powder suspension (a non-porous process) may also provide good results on matt painted walls, as evidenced from the findings of this study. Research suggests that powder suspension (iron oxide formulation) was useful in developing latent marks on painted walls (Lawrie, 2007; Lawrence, et al., 2010), and therefore it was included as a recommended process in the latest practitioner guidelines (Bandey, et al., 2014). Similar results were found in this study, and thus it will continue to be recommended as part of a new sequential workflow for matt paint (Figure 49). It is important to note that the new workflow for matt paint (Figure 49) has been designed using guidelines from CAST (Bandey, et al., 2014), rather than being tested within the laboratory.

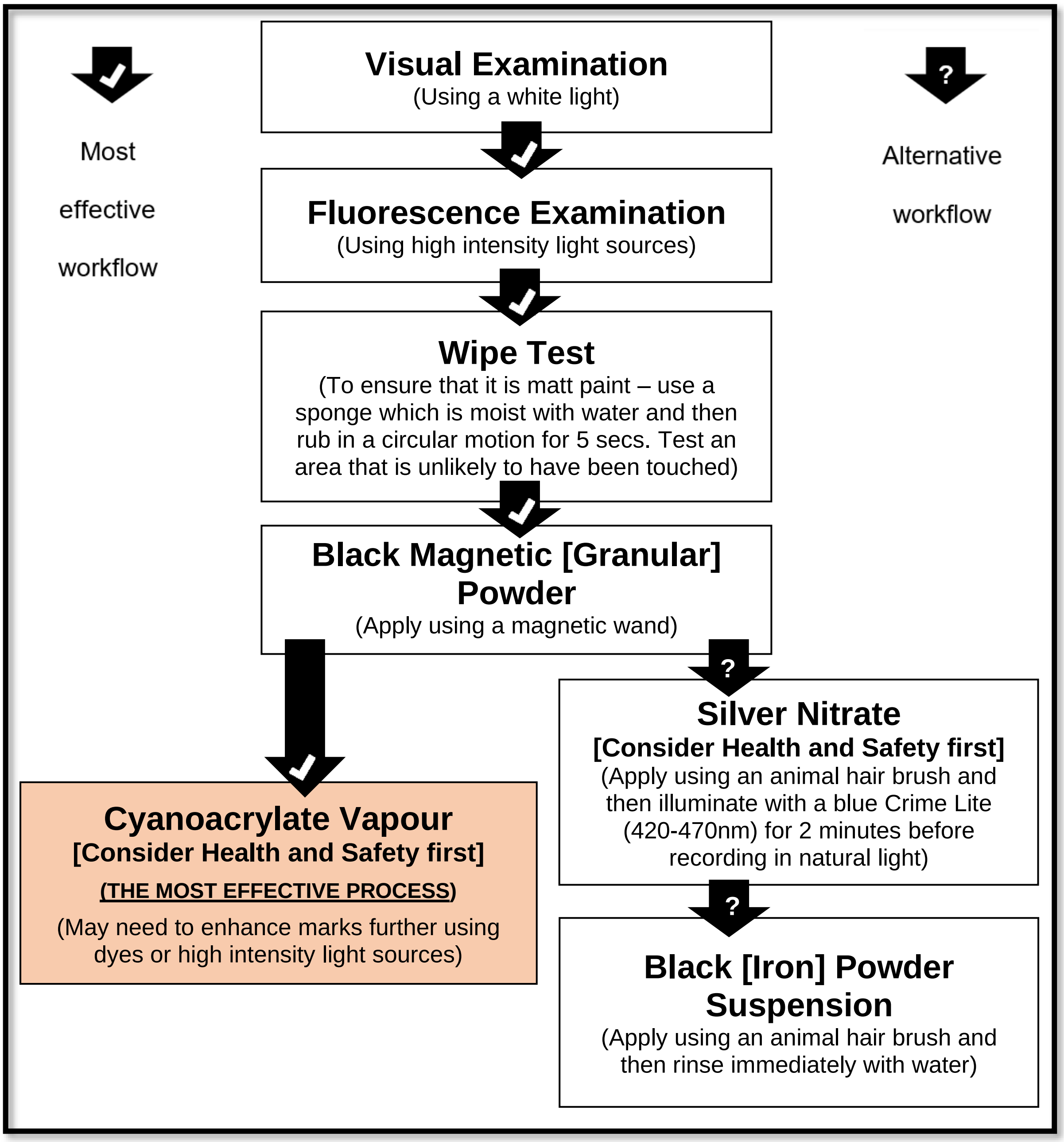

Figure 49 - New flowchart of the recommended sequential processing of matt painted walls for the optimum development of latent fingermarks.

The newly recommended sequential treatment guidelines for matt paint (Figure 49) begins with visual and fluorescence examinations, as per previous guidelines. This is due to these techniques being contactless and non-destructive for both the fingermark and the substrate, in addition to not needing any sample or solution preparation (Charlton, 2009; Kent, 2013a; Bandey, et al., 2014; Bleay and De Puit, 2018).

Any marks that are found should be recorded, via photography, before referring to the sequential treatment guidelines (*ibid*). It is also important to examine walls using visual methods in order to identify a suitable area in which to conduct the 'wipe test'. The new guidelines (Figure 49) involve the newly designed 'wipe test' to establish that the wall is definitely coated with matt paint. The inclusion of this step is to mitigate the 'guesswork' that is currently being conducted by practitioners, to determine the paint type, as highlighted in the survey at the beginning of this research (discussed in Chapter 2 – section 2.2.2.2).

Once the paint type has been established as matt (using the 'wipe test'), the next treatment in the sequential process is black magnetic granular powder. Whilst this technique was not the most effective for matt paint in this study, it is recommended as the first contact method, as it is minimally destructive to latent marks and substrates, providing that it is applied using the correct method (Langford, et al., 2010; Bandey, et al., 2014). This recommendation is also in line with the overall guidance provided by CAST, which states that the least destructive methods should be utilised first, starting with 'liquid free' processes (Bandey, et al., 2014; Bleay and De Puit, 2018). This methodology will allow for some marks to be developed, but will not damage other latent marks, which can be developed using subsequent processes in the sequence. It is important to note that although this is not the most effective method, this is the only process that can be used by CSEs on matt painted walls at volume crimes scenes. It is also vital that CSEs follow the guidelines and only use black magnetic granular powder on painted walls, rather than other powders such as magneta flake (as discussed in section 4.3.3.1.), which are much less effective.

After appropriately recording any marks that were located using black magnetic granular powder, practitioners would then need to make a decision on which process to use next, based upon the circumstances of each individual crime scene. The most effective process to use next is cyanoacrylate vapour, which is the most efficient treatment on matt paint overall, as discussed in section 4.3.3.1. However, it is important to note that heavy powdering may inhibit the quality of any subsequent marks developed with cyanoacrylate vapour (Bandey, et al., 2014).

Therefore, for major crime scenes, it may be prudent to avoid using powders and solely concentrate on cyanoacrylate vapour, which is known to be the most effective process on matt paint (Figure 49). Another point to be considered is that whilst the results from this study showed cyanoacrylate vapour to be an effective process for matt painted walls, the research was not carried out '*in situ*' using a SUPERfume® system. This study used an MVC3000 cyanoacrylate vapour chamber, which provides a much more controlled environment for the development of fingermarks, with constant temperature and humidity (Foster and Freeman, 2017). When developing fingermarks at crime scenes, the same parameters cannot be as easily controlled due to the size of the area being fumed. Therefore, the temperature and humidity are likely to vary throughout the fuming period, which will affect the success of the overall process (Bandey and Kent, 2003). Nevertheless, the SUPERfume® system has shown to be efficient at developing marks '*in situ*', particularly on textured surfaces, where other processes, such as powdering, have been ineffective (Fieldhouse, 2011a). Whilst the results of this research show that cyanoacrylate vapour is the most effective process, it may not suit the circumstances of every crime scene. It is important to bear in mind that if a system, such as SUPERfume® is used '*in situ*', then everything in the room will be subjected to cyanoacrylate vapour, unless carefully protected and sealed in plastic (Bandey and Kent, 2003). This may be problematic if items need to be preserved for alternative treatments. It is impractical to use this process at volume crime scenes, due to need for repairs/redecoration post-treatment.

An additional problem, which may be encountered when using cyanoacrylate vapour to develop marks on walls, is the need to dye the developed marks; especially if the walls are white, or light coloured, which is highly likely (as discussed in section 1.1.3. and shown in Figure 2). As cyanoacrylate vapour produces a white polymer along the ridges of latent marks, it can be difficult to visualise the marks if the painted wall is also white, thus dyes, such as basic yellow 40, will stain the polymer, allowing for better contrast between the mark and the wall, as discussed in section 4.3.3.1. (Ramotowski, 2013c; Bandey, et al. 2014). The dye is relatively messy to apply and requires the walls to be rinsed with water. Thus, not only is there a need to capture the excess liquid, it may also be necessary to redecorate the scene post-treatment (Beaufort-Moore, 2009). In addition to this, not all Police Services have access to the appropriate portable cyanoacrylate fuming systems that can be utilised '*in situ*'. This will prevent practitioners from using this process outside of the laboratory, as it is hazardous to use in an uncontrolled environment, such as a crime scene, without significant health and safety precautions in place (Charlton, 2009).

Therefore, if cyanoacrylate vapour is not viable for use at a scene, then the final option is to use silver nitrate solution, followed by black [iron] powder suspension. Whilst neither of these processes were highly effective on matt paint, as discussed in sections 4.3.2.1, they did each develop some fingermarks. Nevertheless, the possibility of visualising additional marks should be carefully considered alongside the health and safety of personnel and the necessary clean up and repairs required. When silver nitrate is used, the background development of the treated wall will continue to darken (after the optimum contrast is obtained between the background and the fingermarks), leaving dark staining behind (Ramotowski, 2013b; Daluz, 2015). Therefore, significant repairs/redecoration will be needed in order to return the scene to its original state, thus reserving this process for the most serious of crime scenes.

Similar issues will be encountered when using powder suspension '*in situ*' due to it being a very messy process to apply. In addition, the excess solution applied needs to be rinsed off the walls (Bandey, et al., 2014; Bleay, et al., 2017). Therefore, it may be pertinent for practitioners to target specific areas of the walls, which are more likely to contain latent marks, however this information is not always known. On the other hand, it is appreciated that full sequential processing is time consuming and is therefore generally reserved for serious crimes scenes, such as murder (Lee and Gaensslen, 2001).

As mentioned previously, it is important to note that whilst cyanoacrylate vapour was the most effective method at developing fingermarks on matt painted walls, CSEs (who attend scenes on a daily basis) do not have the equipment to use this process (Pepper, 2005; Scenesafe, 2017). Therefore, as the majority of crime scenes are from volume crime types, the painted walls would need to be examined for latent marks using black magnetic [granular] powder, as CSEs routinely carry this (*ibid*). This will have a significant effect on the quality and quantity of fingermarks developed on walls at scenes, and as such needs to be recognised by practitioners. In addition to this, it should be noted that powders are extremely difficult to clean off matt painted walls. Therefore, if powders are used at volume crime scenes they should be targeted at small areas of the wall where the offender/s are highly likely to have touched.

The cost of providing all CSEs with portable cyanoacrylate vapour equipment, coupled with the time needed to develop marks at scenes and the subsequent repairs that would be required post-treatment, means that the routine use of cyanoacrylate vapour at volume crime scenes is not viable. Therefore, for volume crime scenes it is recommended that practitioners use black magnetic granular powder. Other powder types, such as magneta flake, should not be utilised as these are ineffective, as shown in Figure 14 in section 2.4.2.1.

5.3. Guidelines for non-matt paints (silk, bathroom, kitchen, eggshell, etc.)

The current guidelines for practitioners recommend a combination of both porous and non-porous processes for non-matt painted walls, as shown in Figure 50 (Bandey, et al., 2014). These guidelines are also based upon research carried out at CAST, using a range of publications to inform their research (Flynn, et al., 2004; Lawrie, 2007; Fletcher, 2009; Lawrence, et al., 2010; Bleay, et al., 2013; Bleay, et al., 2017).

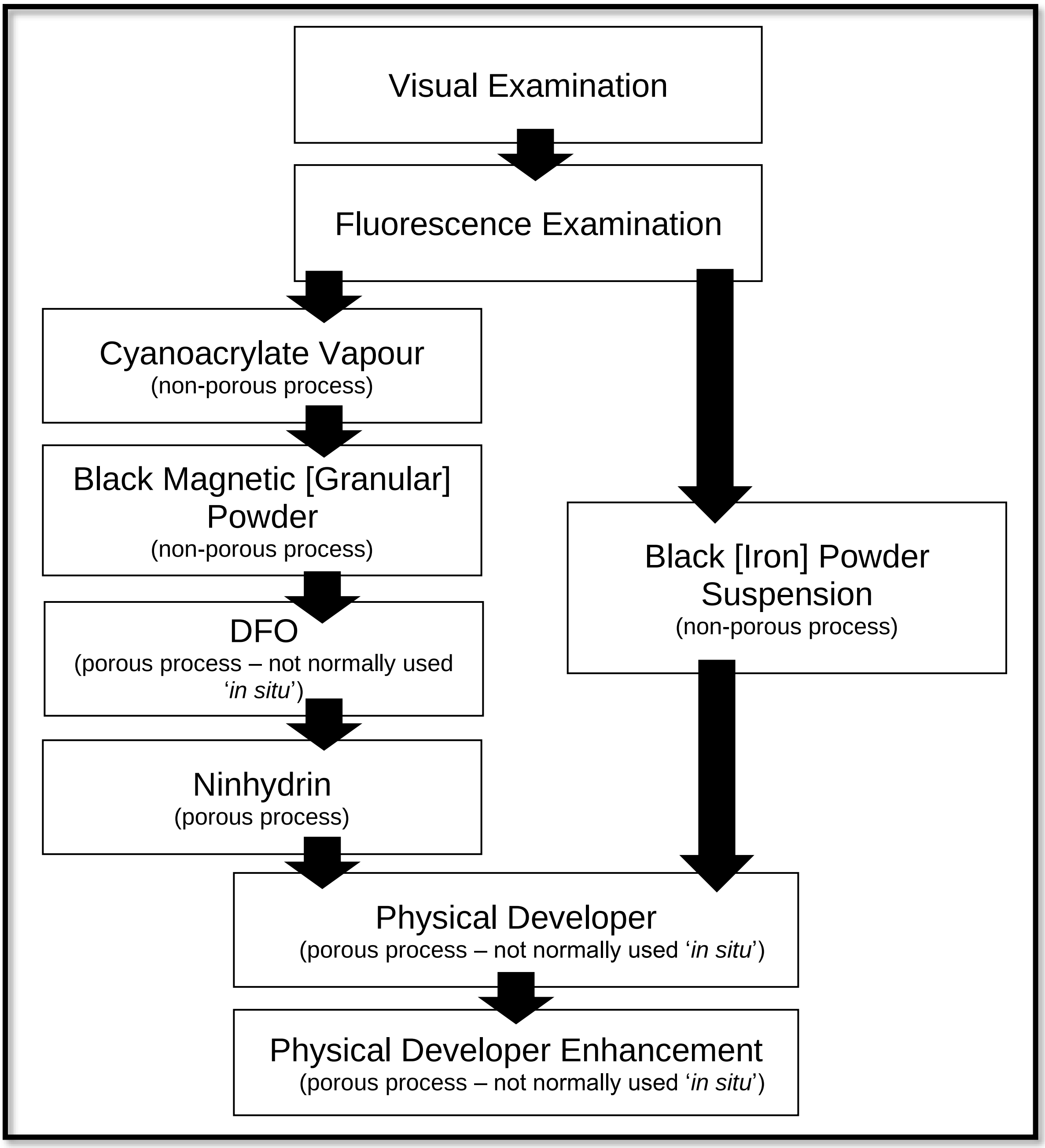

Figure 50 - Flowchart of the current recommended sequential processing of silk painted walls
(adapted from Bandey, et al., 2014).

Findings from this research has shown that porous processes are not effective at developing latent fingermarks on non-matt paints. Therefore, it is recommended that such processes are removed from fingermark development guidelines for all non-matt paints, placing the emphasis on optical methods and non-porous techniques, which are much more effective, as discussed in section 4.3.3.1.

It is important to note however, that the guidelines shown in Figure 50 are specifically for silk (and satin) painted walls. Currently, there are separate guidelines for matt paints and for gloss paints, but other types of paint, such as kitchen, bathroom and eggshell, are not accounted for in the guidelines (Bandey, et al., 2014). Therefore, the recommended sequential workflow presented in this thesis (Figure 51) incorporates all non-matt paints that could be applied to walls (i.e. kitchen, bathroom, eggshell, Duracoat). However, gloss paint is not included, as this is predominantly applied to wood and metallic surfaces.

The new guidelines for non-matt paints (Figure 51) also begin with visual and fluorescence examinations, followed by the wipe test, as per the guidelines for matt paints (Figure 49). Once the paint has been identified as a non-matt paint type, using the wipe test, then the first technique that should be applied in the sequence is black magnetic granular powder. This method was the most effective process overall in developing latent marks on non-matt painted walls, and is in contrast to matt paints, where powders were less effective. The efficacy of black magnetic granular powder on non-matt painted walls is extremely beneficial, as all CSEs have access to this process and therefore it can be applied to the walls at a variety of crime scenes, ranging from serious and major incidents, through to volume crime scenes (Pepper, 2005; Scenesafe, 2017). However, it is necessary to emphasise to CSEs the specificity of the powder to be utilised (black magnetic granular powder), as it is clear from the results of the practitioner questionnaire (Chapter 2 – section 2.2.2.2) that many CSEs are using other powders, regardless of the current guidelines from the Home Office. This highlights a training need for CSEs to ensure that they understand the importance of using appropriate powders according to substrate type.

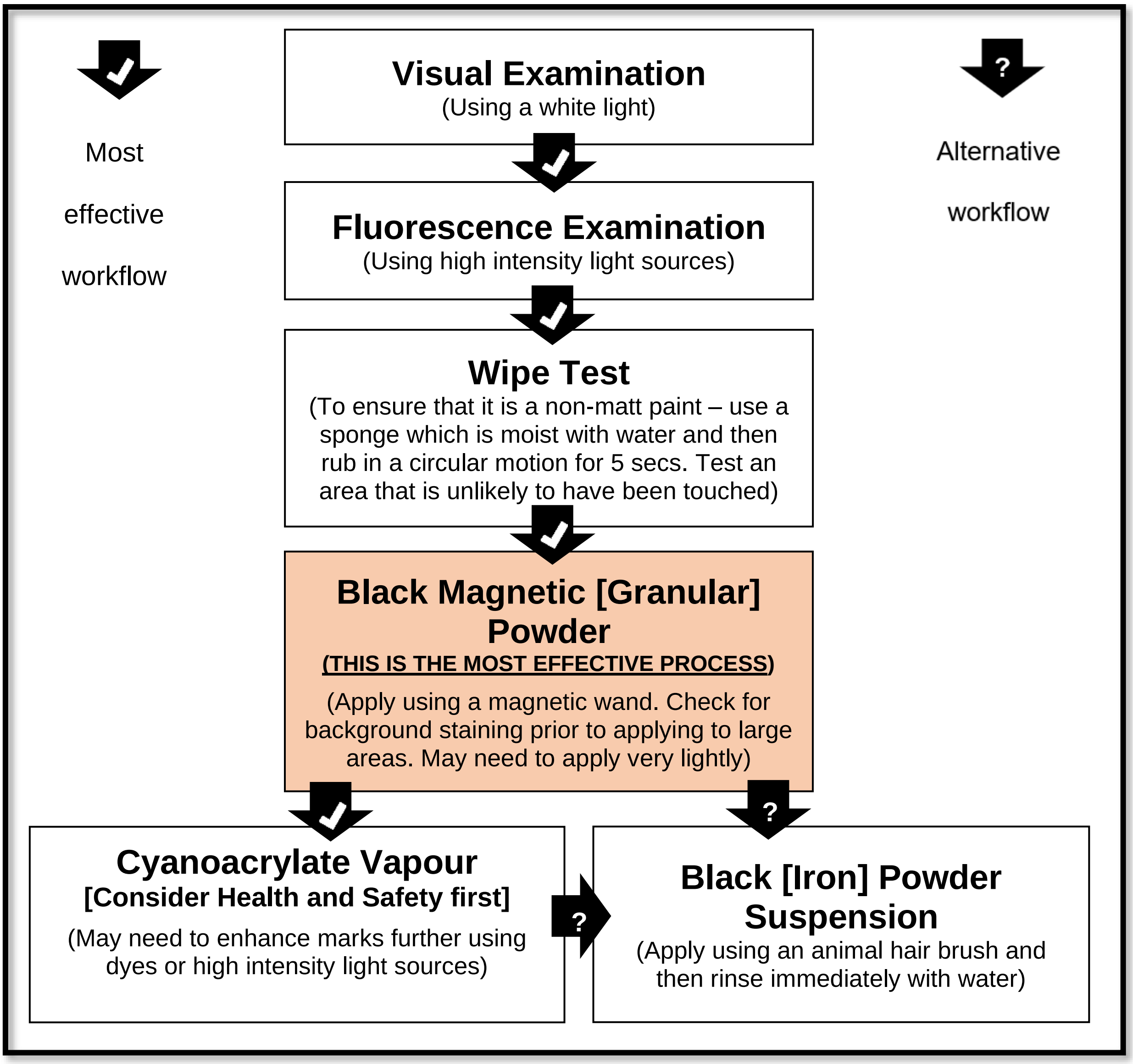

Figure 51 - New flowchart of the recommended sequential processing of non-matt painted walls for the optimum development of latent fingermarks.

Once black magnetic granular powder has been used, and any developed marks recorded, then practitioners will need to make a decision on whether to use cyanoacrylate vapour or black [iron] powder suspension as the next step in the sequential process. When assessing the efficiency of both processes on bathroom paint, the results were very similar. However, when applied to silk paint cyanoacrylate vapour was significantly more effective at developing latent marks, whereas on eggshell paint powder suspension was the most effective process (as shown in Figure 44).

Notwithstanding the use of the wipe test, it would be very difficult for practitioners to be able to distinguish between silk and eggshell paint '*in situ*' in order to utilise the most efficient process for the paint type. Therefore, it may be more effective for practitioners to assume that the paint is silk, rather than eggshell, as the sales data gathered at the start of the research suggests that the majority of paint types purchased by consumers are either matt or silk, with a small amount of bathroom and eggshell paint being bought (Wickes, 2015).

Consequently, the preferred route through the sequential processing scheme for non-matt paints focuses on silk paint and therefore recommends the use of cyanoacrylate vapour after black magnetic granular powder. As discussed in section 5.2, this may only be feasible at serious and major crime scenes, due to the requirement for specialised equipment, and the health and safety concerns with utilising this technique at scenes (Bandey and Kent, 2003; Charlton, 2009; Fieldhouse, 2011a).

In addition to, or in lieu of, cyanoacrylate vapour, it may be beneficial for practitioners to use black [iron] powder suspension at the end of the sequential process. This final technique may develop additional marks to those already enhanced with the previous methods discussed. Whilst black [iron] powder suspension had limited success on silk paint, it was efficient at developing marks on bathroom and eggshell paints. Therefore, practitioners should consider using this method in addition to others when possible. However, as discussed in the previous section, this decision should be carefully considered and rationalised alongside the necessary cleaning requirements when using this process '*in situ*' (Bandey, et al., 2014; Bleay, et al., 2017).

5.4. Conclusion

The aim of this chapter was to establish a set of guidelines detailing the optimum processes to use and the most appropriate sequential order in which to do so. This would fill the current gap in knowledge and assist practitioners in their decision making. The 'wipe test', was introduced, providing quick and consistent results, allowing practitioners to differentiate between matt and non-matt paints. The test can be conducted in a matter of seconds, using inexpensive materials that are readily available in a variety of supermarkets.

Nevertheless, the test is destructive to the paint and therefore should only be carried out in a location that is unlikely to have been touched. The 'wipe test' was therefore inserted into the sequential process flowchart for both matt and non-matt paints, after the optical processes had taken place. The sequential physical and chemical development processes in the current guidelines were re-evaluated according to the results from this research. Whilst some techniques remain in the newly recommended sequential workflow, changes have been suggested for both matt and non-matt paints. The new guidelines could be utilised by practitioners with immediate effect, as the processes listed are already well-established and understood by CSEs and FLOs. However, additional training may be needed, particularly for CSEs, in order to emphasise the importance of adhering to the powders specified in the guidelines.

Chapter 6 - Conclusion of research

The aim of this research was to determine which fingermark development processes are most efficient at developing latent marks on walls that have been painted, and in which sequence such processes should be applied. Chapter 1 reviewed a wide array of literature concerning the development of latent fingermarks which could be utilised for this research, although there was little research that focused on the development of marks on painted substrates. This assisted in filling the void of knowledge and providing a baseline of evidence from which to start designing methodologies for the experimental phases of the study.

The information gained during the literature review highlighted that whilst there are already guidelines for practitioners to follow regarding the development of latent marks on painted walls, these are based on a limited number of studies; some of which were conducted many years ago. Presently, there are a number of supplementary processes that could be applied '*in situ*', some of which are relatively recent additions within the field of fingermark development. This highlighted a large gap in knowledge, which needed to be addressed.

Chapter 2 began by exploring the current methods used by practitioners to develop fingermarks on painted walls. A questionnaire was distributed to a number of appropriate practitioners to gauge the current landscape across the UK and ascertain the most commonly used processes for a range of different crime scenes. The results revealed that the likelihood of painted walls being examined by practitioners increases with the severity of the crime type, which was expected.

However, some surprising results were established from the survey. Firstly, it was noted that many practitioners were unable to identify the type of paint that had been used on the walls of crime scenes, and therefore were either guessing the type, or were not even considering the paint type in their decision-making process. Secondly, practitioners tended to favour a development process (the most popular being magneta flake powder), regardless of whether that process was suitable for use on painted walls. It was clear that these two issues needed to be addressed as part of this research, and thus were explored in detail in Chapters 2, 3 and 4.

The latter part of chapter 2 discussed the results of the preliminary experiments, which were conducted to provide a baseline of evidence that informed later studies (Chapters 3 and 4). It was necessary to establish whether or not painted walls were affected by the composition of the wall. Three main types were investigated (plaster, sealed plasterboard, plain plasterboard), as these wall compositions are the most frequently encountered at scenes. The results and subsequent statistical analysis showed that the wall finish does not affect the development of fingermarks. Consequently, further studies only utilised plain plasterboard as simulated walls that were subsequently painted, as this was more time efficient and cost effective. It was then necessary to ascertain whether or not the type of paint applied to the wall had an effect on the development of deposited latent marks. Data gather from Wickes revealed that the most frequently purchased paints types for walls were matt, silk, bathroom and eggshell. These paints were tested in a study involving a large number of donors (N=30), and the results showed that the type of paint makes a significant difference to the effectiveness of development processes.

The final experiment discussed within Chapter 2 compared brands of the same paint type (i.e. Dulux matt vs. Wickes matt) in order to evaluate whether this affected the quality/quantity of developed fingermarks. The results showed that there are distinct differences between some paint brands of the same paint type, and therefore, this was explored further in Chapter 3.

Chapter 2 also highlighted variations in the donors' results dependent upon the process used. It was found that the marks from some donors were more effectively developed using powders, whereas some showed a preference for ninhydrin. This emphasises the importance of sequential processing, rather than utilising a singular process.

Chapter 3 sought to explain the results found in Chapter 2 using microscopy, SEM and SEM-EDX. It was possible to identify the main differences between paint types, allowing them to be categorised into two coherent groups; matt and non-matt. All of the results showed that whilst there were minor discrepancies between silk, bathroom and eggshell paints (in terms of composition and particle size/shape), these were limited compared to matt paint, which was distinctively different. The particles found within non-matt paints were of uniform size and shape, and were evenly distributed in the binder layer. Conversely, the particles found within matt paint were much larger and varied greatly in size and shape. The particles in matt paint protrude from the binder layer, creating a rough and textured topography. This information was novel, as a study focusing on the topography of painted walls in a forensic context has not been reported or published before. Therefore, a significant gap in knowledge was addressed with the results of these experiments, assisting in the design of future methodologies.

Chapter 3 also explored a novel methodology that could be used '*in situ*' to differentiate between matt and non-matt paints. The results of the practitioner survey in Chapter 2 had highlighted this as an issue, and therefore, it was deemed necessary to design a protocol that practitioners could use to negate the need of guesswork. Hence, an evidence-based, simple, easy and cost-effective method (i.e. the wipe test) was investigated, which proved to be effective.

The findings of this particular study showed that a yellow sponge (that has been moistened with water) should be rubbed in a circular motion on a painted surface for 5 seconds, and if any paint transfer was visible then it could be categorised as a matt paint. If no paint transfer was visible then it could be categorised as a non-matt paint. Thus, this newly developed and novel test was incorporated into the sequential processing flowcharts, which formed part of Chapter 5.

Chapter 4 investigated which processes are most effective at developing fingermarks on different paint types. The first of the experiments in this chapter explored the differences between ninhydrin and indandione, and ascertained the most appropriate time to visualise marks developed with these processes '*in situ*'. The optimum period for visualisation was only 4 hours for indandione, and 1 day for ninhydrin, which is in agreement with the results presented in Chapter 2, but contradicts current guidelines. This was an important finding, as if visualised at the wrong time, the quality and quantity of marks developed with either process would be much lower than if viewed during the correct time frame. Again, these findings regarding the optimum time frame in which to visualise marks developed with ninhydrin or indandione is significant, as there is no literature available to the author's knowledge, thus filling another gap in knowledge.

Experimental work in Chapter 4 concentrated on the investigation of alternative processes that could be applied '*in situ*' to painted walls in crime scenes. A range of techniques were explored (indandione, iodine, silver nitrate and powder suspension) to ascertain whether or not any of these processes were efficient in developing latent fingermarks from a small number of donors (N=6). Silver nitrate and powder suspension were the most effective of the 4 methods tested, however, silver nitrate was only able to develop marks from 2 of the 6 donors. Both indandione and iodine were deemed to be too ineffective, and were eliminated from further experimental work. Therefore, as powder suspension was the only method of the 4 to produce effective and consistent results, this was the only process that was investigated further.

The final experimental work in Chapter 4 focussed on the most effective processes from all previous experiments (black magnetic granular powder, black iron powder suspension and ninhydrin, with the addition of cyanoacrylate vapour). These were examined in detail, using a large pool of donors (N=30) to determine which techniques should be recommended for matt and non-matt paints. Both black magnetic granular powder and cyanoacrylate vapour proved to be the most efficient in developing marks on both matt and non-matt walls. Powder suspension was also effective on eggshell and bathroom paints, but less so on matt and silk. However, ninhydrin was ineffective on all paint types and was therefore discounted from further investigation. The results of this final study were then utilised to inform the guidelines that were presented in Chapter 5.

The final section of this research culminated in the proposal of new guidelines for practitioners, detailing efficient sequential processes for both matt and non-matt paints. The new guidelines also incorporated 'newer' paint types, such as eggshell and bathroom paints, which are not currently considered within the existing guidelines. The current guidelines were discussed, explaining why particular elements should be removed, and then the newly designed guidelines were outlined, supported by evidence gathered throughout this research.

6.1. Limitations of this research

There were limitations to these experiments due to the number of possible variables that could be tested. Firstly, the use of simulated walls, rather than utilising actual walls, should be highlighted, and therefore the implications that full wall construction may have on latent fingermarks (i.e. temperature fluctuations, humidity and air flow) has not been taken into account (Barry, 1999; Emmitt and Gorse, 2014). However, due to practical reasons it was not feasible to conduct preliminary experiments on full sized walls of varying construction. Thus, simulated walls that were constructed using realistic materials were used in this study.

In addition to this, the Department for Communities and Local Government (2012) indicated that the age range of houses in the UK differs considerably and therefore the overall wall construction and finish still needs to be considered, despite this study highlighting no significant differences between the wall finishes that were tested under laboratory conditions.

The number of paint types examined was limited to the 4 most frequently sold, as highlighted from the data supplied by Wickes (2015). However, there are many additional paint types that might be encountered at a crime scene, which were not explored, such as ‘Endurance’, ‘Indulgence’, ‘One Coat’ and ‘Soft Sheen’ (Crown, 2013; Dulux, 2015a; Johnstone’s, 2016; Wickes, 2016). As this study aimed to explore paint types in detail, it was necessary to limit the number of paint types examined to prevent the research from becoming unmanageable. The application of the paint to the simulated walls was also limited to one method (i.e. rollers) for the same reason as above, although it is acknowledged that other application methods (i.e. paint brushes and paint pads) are available, in addition to other style rollers. In addition to this, the number of paint brands tested in this experiment was also limited to ensure that the research was conducted at a manageable level. The number of paints brands available for each paint type is extremely large (Crown, 2013; Dulux, 2015a; Johnstone’s, 2016; Wickes, 2016), and therefore it would not be feasible to test all of these in a research study of this size.

The composition of fingermarks was also controlled in this experiment, as the inter- and intra-variability of donated marks vary significantly (Frick, et al., 2013; Stubbs, et al., 2015). Synthetic amino acid and sebaceous reference print pads were used in some of these experiments to control this variable; however, the quality of such pads differ and should not be assumed to behave as real fingermarks (Sears, et al., 2012). Nevertheless, for the initial stages of research, such as the preliminary experiments, they were acceptable to use as they can be effective indicators as to whether or not the research is worth progressing (Sears, et al., 2012; International Fingerprint Research Group, 2014).

Nevertheless, in other experiments, donor marks were used to test this variable. The International Fingerprint Research Group (IFRG) (2014) recommends that 5-15 donors are used for optimisation and comparison studies, and 20 donors for validation and pseudo-operational trials. On the contrary, The Home Office Centre for Applied Science and Technology (CAST) recommends the use of 40 donors (Sears, et al., 2012). This study had 30 donors, due to the size of the simulated walls used, which sits between the two recommended numbers from the IFRG and CAST. Whilst fingermarks remained anonymous once deposited, the donors were recruited to provide a mix of age, gender, ethnicity and diet, as recommended (Sears, et al., 2012; International Fingerprint Research Group, 2014); although fingerprint secretion levels were unknown.

There were also limitations relating to optical microscopy, which like many forms of microscopy, is subjective and therefore susceptible to inter-personal variability (Thoonen, et al*.,* 2016). Each observer may visualise and note differing characteristics, which may also vary with experience. Nevertheless, the main disadvantage of optical microscopy is that the magnification level generally available is limited, which means that images lack the finer detail that can be gained from other forms of microscopy (Hochleitner, et al*.,* 2003; Ramotowski, 2013e).

Therefore, SEM is much more beneficial, as it allows for much more detailed analysis to be undertaken regarding the topography of the surface structure. Nevertheless, there are limitations with the use of SEM and SEM-EDX when analysing the relationship between paint and fingermarks, particularly for casework. Whilst some microscopy techniques can be carried out by personnel with basic training '*in situ*', SEM is not portable. Consequently, this means that samples would need to be taken from the scene to the laboratory where the analysis would be carried out. In addition to this, some sample preparation is needed whereby a conductive coating, usually gold, is applied to each sample, which is expensive (SWGMAT, 2002).

Besides this, the SEM-EDX instrument is expensive to purchase and should only be operated by trained staff, thus confining this technique to specialised forensic laboratories, rather than being available to all Police CSEs and fingerprint laboratories.

The introduction of the 'wipe test' is beneficial to practitioners, as it will assist them in establishing the paint type whilst '*in situ*' in a simple and quick, yet effective manner. However, there are also limitations to the experimental work conducted on the 'wipe tests' which need to be taken into consideration. Firstly, only 6 cleaning materials were tested, which is only a small representation of all materials that can be purchased in the UK. The number of cleaning materials was limited to 6 in order that these could be tested in detail using a variety of methodologies and applied to the necessary paint types and brands used in this research. However, the range of cleaning materials was specifically chosen to gain a representational sample of all that are available to consumers in the UK. As the tests will be conducted '*in situ*' by practitioners, they need to use equipment that is readily available, or could be easily purchased, allowing for the presumptive test to be initiated by Police Services immediately, without the need to purchase expensive or intricate instrumentation. Hence the recommendation for yellow sponges to be used, which are cheap, easy to use and cost-effective.

Other limitations related to solution formulations, heating temperatures and timings, which were kept consistent throughout the study to solely focus on those that would have affected practitioners working in the field. Therefore, it is possible that other methodologies may be more effective when used '*in situ*', however the approaches chosen for these experiments are those recommended by CAST, which have been thoroughly researched (Bandey, et al., 2014; Bleay, et al., 2017).

There were also limitations regarding the use of dye stains, which affected the grading of marks developed with cyanoacrylate vapour (stained with BY40) due to background staining. In some cases, the background fluoresced more than the actual marks, making it difficult to fully assess the quality of the developed mark. It is therefore important to consider a variety of dyes to determine which (if any) have an appropriate Stokes shift to provide contrast with the painted wall (Ramotowski, 2013c). To counteract this issue, it would be pertinent in future studies to consider the use of one-step fluorescent cyanoacrylate, such as Polycyano or Lumicyano^{TM}, which would negate the need to use any dye stains. Oblique lighting was considered, but it was difficult to gain a good contrast between the cyanoacrylate developed marks and the background.

Another limitation that needs to be highlighted is that the sequential processing guidelines have been developed using previous research and guidance from CAST, rather than being rigorously tested in the laboratory. It was deemed impractical to test every possible sequential process in detail (as per other studies untaken within this research), due to time constraints, the quantity of simulated boards and number of donated fingermarks required. Nevertheless, each set of sequential processes produced for practitioners follow the same set of guidelines, which begin with optical methods, followed by liquid-free techniques, followed by solvent-based processes and finally water-based methods (Bandey, et al., 2014). Therefore, as this research follows the same set of guidelines, the newly recommended sequential processes are consistent with others and thus can be easily understood and applied by practitioners.

6.2. Areas for future research

As mentioned within the limitations of this study, there are a number of areas that require further research in the future. Firstly, it would be pertinent to further research the use of high intensity light sources on painted walls. As mentioned previously (section 1.5.1.), this research did not examine high intensity light sources in any detail, as it will always be the first step in a sequential process, due to its non-destructive properties.

Nevertheless, it would be advantageous to explore which wavelengths of light are most effective at developing fingermarks on painted walls, dependent upon the different residues that may be present within the marks.

In addition to this, it would be beneficial to explore the use of Lumicyano™ and Polycyano in lieu of using traditional cyanoacrylate vapour and basic yellow 40. This may counteract some of the issues with fluorescence encountered in this study and could be effective on painted walls, particularly matt. Nevertheless, the difference between using such products within a controlled chamber in a laboratory and using them '*in situ*' may be significant and should be taken into consideration in any future research. If this is the case, then further research should be conducted into the use of reflected UV lighting to visualise cyanoacrylate developed fingermarks. Reflected UV lighting was attempted within this study, but was not as successful at enhancing the developed marks as BY40 dye staining was. Therefore, only the dyed marks were reported on in this research.

Another area to be explored in more depth is the use of silver nitrate on painted walls. Whilst this process was investigated in this study, it would be beneficial to determine why it was highly effective for some donor marks and not for others, by expanding on this section of the research in more detail. It would also be pertinent to undertake additional studies on the use of iodine with benzoflavone on contemporary painted walls to ascertain whether or not the benzoflavone increases the effectiveness of the process. Another suggestion would be to alter the formulation of ninhydrin to include a slower evaporating solvent. This would allow more time for ninhydrin to react with the amino acids present in the fingermark residue. In addition to this, the use of gelatin lifters should be investigated as part of a future research project (as discussed in section 1.5.2.2.2.). They are simple, quick and easy to use '*in situ*', and therefore unlike most other processes, it could be an ideal process to utilise on painted walls by either CSEs or FLOs at both volume and major crime scenes.

Other areas for future research could include the use of multiple paint layers consisting of different paint types. It is important to ascertain whether or not this has an impact on the topography of the final paint layer, as this may have significant implications for the effectiveness of the processes used. It would be particularly beneficial to explore walls that have undercoats of matt paint, followed by layers of non-matt paint, as this may affect the overall texture. Another suggestion for future research would be the inclusion of more unusual paint types, such as ‘Endurance’, ‘Indulgence’, ‘One Coat’ and ‘Soft Sheen’. It would be beneficial for practitioners if all types of paint could be categorised into groups, with an appropriate set of guidelines developed to inform the creation of fingermark recovery strategies.

It is also important to note that whilst this research has explored the effectiveness of development processes on walls coated with contemporary paints, the composition of paints are likely to change over time. This has been seen recently with the European Union introducing legislation to limit the harmful VOC levels in paint, thus reducing VOC levels entering the environment. Therefore, it will be necessary to repeat this research again in the future if the composition of paints change due to advances in technology or changes in legislation.

Nevertheless, at the present time, the research presented in this thesis is the most comprehensive piece of work to have been carried out exploring the development of latent fingermarks on painted walls. This research has presented new knowledge and novel ideas to the fingerprint community and fills many gaps in knowledge. However, the primary aim of this research was to assist practitioners working in the field, and therefore it is hoped that the results of this study and the newly created guidelines will provide an evidence-base on which to develop future fingermark development strategies, which are successful.

7. References

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Appendix 1 – Practitioner questionnaire

Anglia Ruskin University

Developing fingermarks on walls

1. Which Police Service are you employed by?

2. What is your current position?

Other (please specify)

3. How long have you worked in your current role?

- 0-2 years
- 3-5 years
- 6-10 years
- 11-15 years
- 16 years or more

4. How often do you attend crime scenes?

- Never/very rarely
- Once/twice a year
- Between 3 and 6 times a year
- Once/twice a month
- Once/twice a week
- Once per working day
- Several per working day

5. What type of crime scene might you be called to attend? ***(please select all that apply)***

- Car crime (theft from, theft of motor vehicle, minor collision etc)
- Burglary crime (dwelling, other)
- Criminal damage
- Armed robbery and ram raids
- Arson
- Violence against person (ABH, GBH, robbery etc)
- Sexual Offences
- Suspicious deaths

6. What is your main role at a crime scene?

Other (please specify)

7. What would normally be your method of choice in developing fingermarks 'in situ' at the following crime scenes? *(please leave any blank that do not apply to you)*

	Aluminium and other flake powders	Magnetic powders	Conventional granular powders (Bristol Black etc)	Light source examination	Chemical treatments for porous surfaces	Chemical treatments for non-porous surfaces
Car crime	☐	☐	☐	☐	☐	☐
Burglary crime	☐	☐	☐	☐	☐	☐
Criminal Damage	☐	☐	☐	☐	☐	☐
Armed robbery and ram raids	☐	☐	☐	☐	☐	☐
Arson	☐	☐	☐	☐	☐	☐
Violence against person	☐	☐	☐	☐	☐	☐
Sexual Offences	☐	☐	☐	☐	☐	☐
Suspicious deaths	☐	☐	☐	☐	☐	☐

Other (please specify the technique and scene types in which you would use it)

8. At what type of crime scene would you normally consider examining the walls of the scene for fingermarks? *(please select all that apply)*

- ☐ Car crime
- ☐ Burglary crime
- ☐ Criminal Damage
- ☐ Armed robbery and ram raids
- ☐ Arson
- ☐ Violence against person
- ☐ Sexual offences
- ☐ Suspicious death

9. How often would you estimate that you examine the walls of a crime scene for fingermarks?

- ○ Never/rarely
- ○ Once/twice a year
- ○ Between 3 and 6 times a year
- ○ Once/twice a month
- ○ Once/twice a week
- ○ Once per working day
- ○ Several per working day

10. Does the type of paint used on the walls have any effect on the decisions you make as to which development technique you will use?

If so, how would you ascertain what the paint type is, and which method to use?

11. On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on *MATT* painted walls at crime scenes?

	1	2	3	4	5	6	7	8	9	10
Light sources examination	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Aluminium and other flake powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Magnetic powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Conventional granular powders (Bristol Black etc)	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Powder suspensions	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
DFO and Ninhydrin	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Other	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										

12. On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on *SILK* painted walls at crime scenes?

	1	2	3	4	5	6	7	8	9	10
Light sources examination	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Aluminium and other flake powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Magnetic powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Conventional granular powders (Bristol Black etc)	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Powder suspensions	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
DFO and Ninhydrin	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Other	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										

13. On a scale of 1 to 10 (with 10 being the best), how well do you think the following techniques perform when used on *KITCHEN / BATHROOM* painted walls at crime scenes?

	1	2	3	4	5	6	7	8	9	10
Light sources examination	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Aluminium and other flake powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Magnetic powders	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Conventional granular powders (Bristol Black etc)	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Powder suspensions	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
DFO and Ninhydrin	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										
Other	○	○	○	○	○	○	○	○	○	○
Please specify which one/s										

14. What would be your preferred method of gaining fingermarks from walls and why?

15. How much of a wall would you examine?

What is the reason behind your decision?

16. What do you think are the main issues preventing examiners from gaining more fingermarks from walls?

17. Is there a need for something to be developed to assist examiners in gaining more fingermarks from walls?

If yes, what would be ideal?

Appendix 2 – Example chart to show distribution of results

This chart is an example to show the distribution of data gathered in this study. It is clear from this chart that the data is positively skewed, and does not show a normal distribution. Therefore, the data is non-parametric and thus appropriate statistical tests, such as the Mann-Whitney U and Kruskal-Wallis tests, were applied.

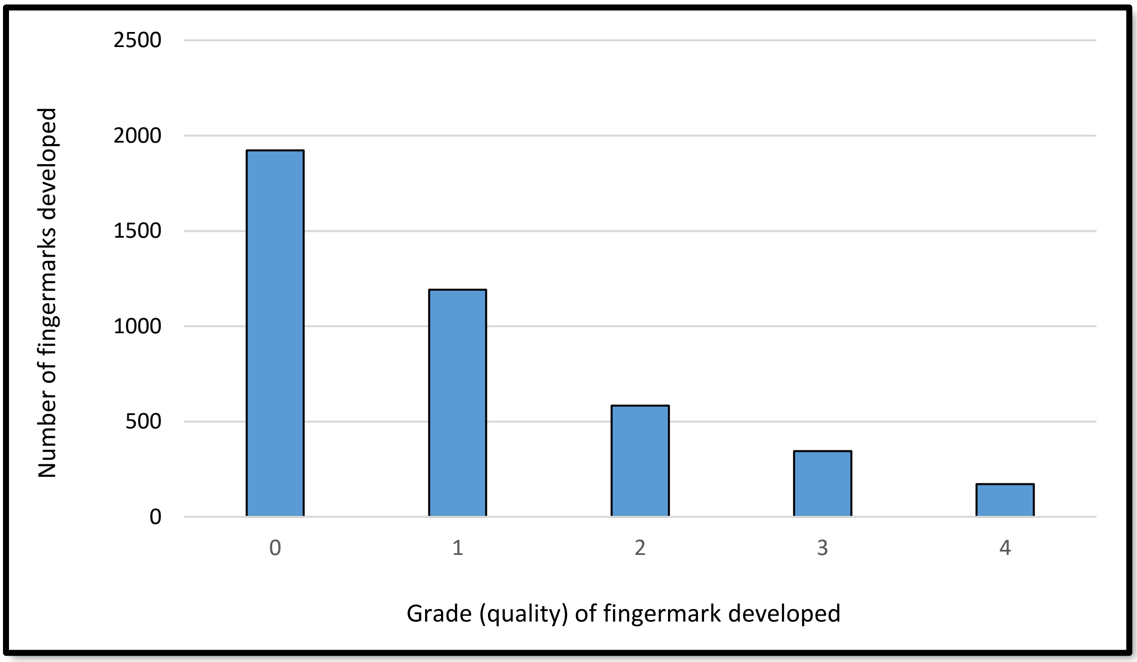

Figure 52 - An example chart to show the distribution of data collected during this study (non-parametric)

Appendix 3 – Chart comparing the range of particle sizes (widths)

This chart displays the size of particle widths from matt, silk, bathroom and eggshell paints, complementing Figure 28, which displays the size of particle lengths.

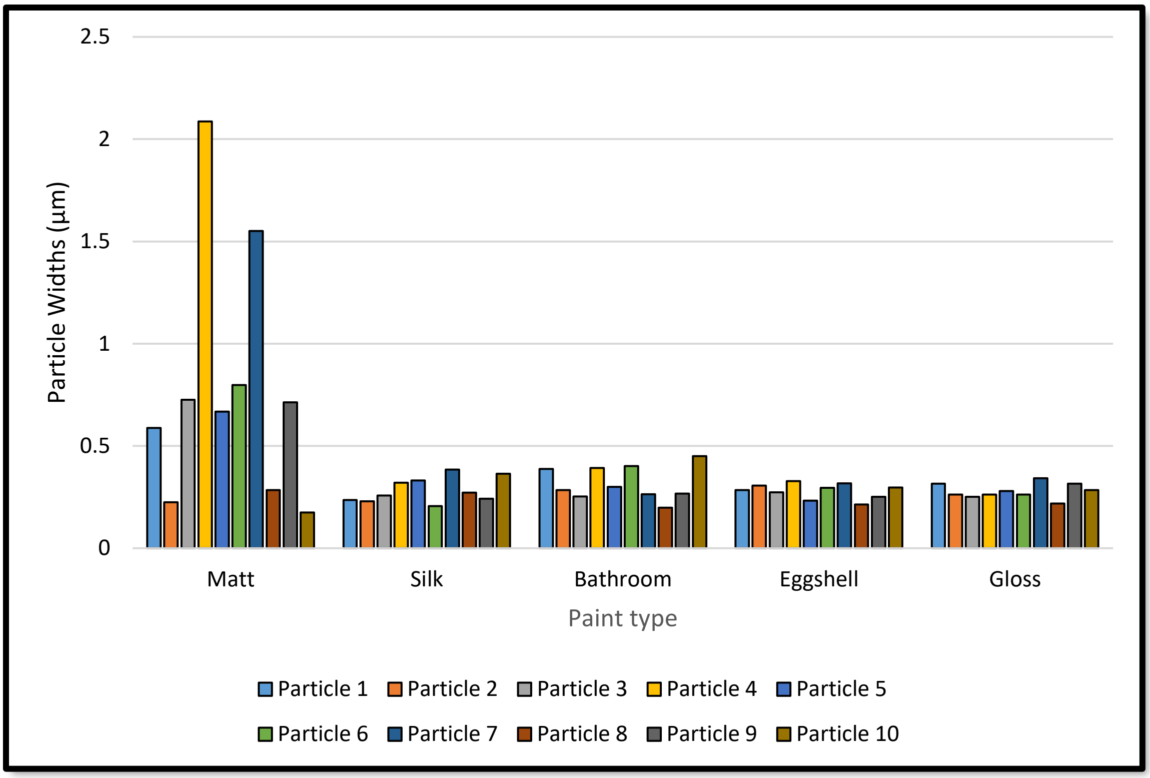

Figure 53 - Chart comparing the range of particle sizes (width) from different paint types